Findings on environmental flow needs in the lower Neches River to mitigate effects of climate change on its ecology

Revised Final Report to: Big Thicket National Preserve,

US National Park Service

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Executive Summary

In 2009, the US National Park Service's Big Thicket National Preserve acquired a 5,900-acre wetland complex, originally known as the Lower Cypress Tract and now named the Beaumont Unit. This tract contains wetland habitats that rank among the most rapidly vanishing within the United States, including cypress-tupelo swamp and Southeastern freshwater marshes. Nearly all of the tract's hardwoods are secondary growth, because the area was extensively logged during the early 1900s. The lower Neches River and sloughs draining the study area support a diverse aquatic fauna, however this biota is still recovering from pollution impacts that reached their peak in the early 1970s. In addition, dams constructed in the upper Neches Basin in the 1950s and 1960s (creating B.A. Steinhagen and Sam Rayburn reservoirs) appear to have led to extirpation of the native population of paddlefish (*Polyodon spathula*) in the Neches River. In 2003, a permanent saltwater barrier was constructed on the river just above the city of Beaumont to replace temporary barriers that had been operated during times of decreased flow. The permanent barrier preserves water quality upstream by preventing intrusion of the saltwater wedge; however, it also reduces delivery of freshwater to the river and associated freshwater wetlands downstream from the barrier. The lower Neches River serves as the receiving water body for effluent from the MeadWestvaco kraft pulp and paper mill in Evadale, Texas. Paper mill effluent is difficult to treat and often overloads systems with dissolved organic matter that causes high biochemical oxygen demand that can reduce dissolved oxygen below levels required to sustain aquatic life.

Given the high value of the wetland ecosystems and biodiversity associated with the Beaumont Unit and lower Neches River, the prior and current anthropogenic impacts, and model projections that predict sea-level rise in the northwestern Gulf of Mexico coast (3.6–9.5 mm per year), a project was initiated to evaluate environmental flow needs for the lower Neches River adjacent to a portion of the Beaumont Unit that lies downstream from the saltwater barrier. Environmental flows have been defined by the Texas Legislature (Senate Bill 3, 2008) as "*a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific* *location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."* Under the mandate of Texas Senate Bill 3, a Sabine/Neches stakeholder committee and a science team studied environmental flow needs for the basin and provided recommendations to the Texas Commission on Environmental Quality (TCEQ). The TCEQ subsequently drafted and implemented environmental flow standards for locations within the basin. However, no flow recommendations were made for the stretch of the Neches River between the saltwater barrier north of Beaumont and Sabine Lake.

This report contains several sets of findings in addition to recommendations for an environmental flow regime for the lower Neches River (below the Beaumont Saltwater Barrier). Findings from a field investigation of hydrology, environmental conditions, and fish assemblages during a period that included major drought is interpreted the context of environmental flows and current human impacts to the ecosystems. The literature was surveyed for life history and tolerance information of Texas fishes to identify species that can serve as indicators of water quality and environmental flow requirements for the ecosystems of the study area. The flows for three gages for which there are long-term datasets were analyzed in relation to their combined contributions to flow at the Neches River Saltwater Barrier gage during the years for which records exist, and these findings were evaluated in the context of an environmental flow regime. For the gage established at the Saltwater Barrier in 2003, data from three upstream gages were used to extrapolate a longer-term flow record. Hydrologic separation of environmental flow components and biological overlay analysis was performed for the Saltwater Barrier gage to derive an environmental flow regime for the lower Neches River. Finally, environmental flow recommendations from the Texas SB3 process, including TCEQ's environmental flow standards, were evaluated for two upstream gage locations.

The field investigation was conducted in 2011 and 2012. In 2011 Texas experienced record annual drought that heightened concerns for environmental flows to sustain fluvial and estuarine ecosystems in the face of increasing human need for freshwater. Fish assemblage and water quality data were analyzed to determine effects of drought and low flows on the lower Neches River above and below a saltwater barrier near the city of Beaumont, Texas. Sites within the Neches River and bayous draining the study area were sampled during the latter stages of the drought in the fall 2011 and again during the summer 2012 after intervals with rainfall. During fall 2011, when there was little or no downstream flow from the Saltwater Barrier, salinity was relatively high; whereas salinity during summer 2012 never rose above approximately 1.5 ppt. Fish species richness was always higher with more indicator species present at sites above the barrier regardless of whether or not the barrier was open or closed. During periods of low flow, salinity increased and dissolved oxygen decreased below the saltwater barrier. This environmental degradation reduced diversity of fish assemblages with sensitive freshwater species rare or absent.

The recommended subsistence flows were not met during the drought of 2011 or during a part of 2012. To maintain water quality that sustains native biodiversity within the study, subsistence flows must be allowed to pass below the saltwater barrier during severe droughts, such as the one experienced during 2011-2012. These flows did not occur in 2011, because the barrier remained closed for long periods in order to protect water quality at locations upstream for diversion to the city of Beaumont. Under current projections for climate change and sea level rise, the problem of saltwater intrusion and lack of flushing flows within the lower Neches River and sloughs within the southern portion of the Beaumont Unit will be exacerbated in the future, and therefore, subsistence flows likely would need to be increased in order to maintain current freshwater wetland vegetation communities within the study region. Moreover, the absence of subsistence flows passing to reaches below the saltwater barrier during times of drought results in overloading of dissolved organic matter from the paper mill discharge that harms aquatic life. Several recommendations are made for future monitoring and assessment for protection of the native biota of the lower Neches River and the area of Big Thicket Preserve Beaumont Unit lying downstream from the Saltwater Barrier.

Introduction

On April 15, 2009, The Conservation Fund made the largest donation of land that Big Thicket National Preserve (BTNP) has ever received, nearly 6,600 acres of cypress-tupelo swamp, bottomland hardwood forest, and freshwater marsh. Most of the donated lands are in a 5,900-acre wetlands complex called the Lower Cypress Tract (now named the Beaumont Unit). Prior to acquisition of these lands, the BTNP did not manage lands that could be said to be predominantly estuarine or coastal, thus, the Beaumont Unit represents a new ecotype for the agency to manage. These new resources provide a great opportunity for protection of wetland habitat and for environmental education. However, the southern portion of the Beaumont Unit may be vulnerable to effects of climate change that have been identified for coastal, riverine, and estuarine ecosystems, and are also subject to impacts from urbanization, agriculture, industry, and water use.

This study address conditions within the southern portion of the Beaumont Unit, an area that borders the east bank of the lower Neches River from a location near the permanent saltwater barrier to near Interstate 10 in the south (Figure 1). A small segment of the new tract is located on the west bank of the river a few miles south of the saltwater barrier and near the northeast limit of the city of Beaumont (Figure 1). Vegetation communities within the study area are diverse (DESCO Environmental Consultants, LP 2012), with dominant assemblages characterized as cypress-tupelo swamp, bottomland hardwood forest, and freshwater marsh, which are rapidly vanishing wetland habitats and among the most severely altered ecosystems in the United States (LNVA 2010, Hoeppner and Rose 2011). Preservation of these habitats is crucial to the maintenance of the local ecosystem; they function to maintain water quality, recharge groundwater, and stabilize water supplies by mitigating flood and drought effects (Mitsch and Gosselink 2000). In addition, these swamps and forests create habitat for a variety of wildlife, including many endangered bird and mammal species (LNVA 2010). Many coastal areas, including extensive areas in Louisiana, have already experienced the loss and deterioration of such habitats.

Figure 1. Map showing location of the study area (outlined in green) of the southern portion of the Beaumont Unit of the Big Thicket Preserve system in East Texas.

The study area lies within the Coastal Management Zone of the Texas General Land Office, and is influenced both by freshwater releases in the Neches River and saltwater intrusion and tides from Sabine Lake and the Gulf of Mexico. Resource stewards at Big Thicket National Preserve now have a new coastal resource to manage, with new challenges, and timely opportunities to develop mitigation for climate change. Decreased freshwater inflow results in greater saltwater intrusion upstream that threatens salt-sensitive habitats, such as marshes and cypress-tupelo swamps (Root and Nichols 1998, Shaffer et al. 2009, Stiller 2009). Under the impact of increased saltwater intrusion, forest structure and growth potential of the dominant trees changes in these ecosystems (Krauss et al. 2009). In South Carolina coastal wetlands, bald cypress growth declined at average annual salinity of 2.0 ppt (Krauss et al. 2009). Two sites with salinities of 2.1 and 3.4 ppt converted from forested wetland to an understory marsh within four years. Sites with lower salinities (2.0 ppt) converted to marshland at a slower rate, but exhibited signs of degradation. In another study, Hackney et al. (2007) identified 2.0 ppt as the salinity threshold for a habitat to convert from a freshwater swamp forest into oligohaline and brackish marshes in North Carolina.

Saltwater intrusion also affects aquatic fish and macroinvertebrate community composition and species distributions (Purcell et al. 2010). A variety of environmental factors influence the structure of fish assemblages of coastal streams, but salinity generally is the underlying abiotic environmental driver of patterns (Gelwick et al. 2001, Martino and Able 2003). An increase in salinity generally leads to greater abundance of saltwater species, alterations in predator-prey interactions and recruitment, and detrimental consequences for migratory fish that require freshwater habitats for a portion of their life cycle. Low abundance of freshwater species in saline environments can be attributed to osmotic stress that can lead to mortality after prolonged exposure (Renfro 1959). Some freshwater fish species have adaptations for dealing with salinity fluctuations, including metabolic rate alteration, oxygen consumption, movement, and water balance adjustment. However, freshwater fish are only capable of reducing the osmotic gradient up to the isosmotic point (approximately 9 ppt for most freshwater species). Beyond this isosmotic point, most fish have increasing difficulty, or are incapable of reducing the osmotic gradient. Although many freshwater fish can tolerate salinity levels higher than 9 ppt, prolonged exposure beyond the isosmotic point requires an extensive use of energy and can result in deterioration of cell function (Peterson and Meador 1994). Many estuarine and freshwater fish migrate across salinity gradients between rivers and estuaries; however, these migrations usually are of short duration (Peterson and Meador 1994, Gelwick et al. 2001).

For rivers that flow directly into the Gulf of Mexico, decreasing freshwater inflow results in saltwater intrusion that may extend several kilometers upstream. It is for this reason that a saltwater barrier was installed on the Lower Neches River in 2003. This barrier preserves water quality upstream by preventing intrusion of the saltwater wedge; however, it also reduces delivery of freshwater to the river and associated freshwater wetlands located downstream from the barrier (Nickerson 1998, GC-CESU 2011). In addition, the US Army Corps of Engineers (USACE) has plans to deepen the navigational channel from the Gulf of Mexico to the Port of Beaumont from 40 to 48 feet which will magnify the influence of tides and salinity on these new Preserve lands (Brown and Stokes 2009).

Decreasing freshwater flow not only threatens to increase salinity levels but also to increase pollutant concentrations. Below the Saltwater Barrier, the lower Neches River serves as the receiving water body for effluent from the MeadWestvaco paper mill in Evadale, Texas (Figure 2). Decreasing freshwater flows in the lower Neches River reduces dilution of paper mill effluent. Paper mill effluent is among the most challenging to treat and typically results in the overloading of dissolved organic matter which is usually associated with high biochemical and chemical oxygen demands (Antony et al. 2012). High biochemical oxygen demand can cause marked decreases in dissolved oxygen below levels required for sustaining aquatic life (Lima Neto et al. 2007).

INFORMATION SECTION

MEADWESTVACO TEXAS, L.P., which operates Evadale Mill, A Kraft pulp and paper mill, has applied for the renewal of TPDES Permit No. WQ0000493000 with a major amendment to authorize a reduction in the monitoring frequency for: (a) adsorbable organic halides (AOX) at Outfalls 001 and 01a from once per week to once per year, (b) chloroform at Outfalls 101 and 201 from once per month to once per quarter, (c) 2,3,7,8-TCDF, 3,4,5-Trichlorocatechol, 3,4,5-Trichloroguaiacol, 3,4,6-Trichlorocatechol, 3,4,6-Trichloroguaiacol, 4,5,6-Trichloroguaiacol, Tetrachlorocatechol, Tetrachloroguaiacol, Trichlorosyringol, 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD), 2,4,5-Trichlorophenol, 2,4,6-Trichlorophenol, 2,3,4,6-Tetrachlorophenol, and Pentachlorophenol at Outfalls 101 and 201 from once per quarter to once per year, and (d) TCDD Equivalents at Outfalls 001 and 01a from once per quarter to once per year. The current permit authorizes the discharge of treated process wastewater commingled with cooling water, domestic wastewater, storm water runoff, and previously monitored effluents (bleach plant effluent via internal outfalls 101 and 201) at a daily average flow not to exceed 65,000,000 gallons per day via Outfalls 001 and 01a; storm water runoff commingled with previously monitored effluent (filter backwash water via internal Outfall 102), utility wastewater, periodic overflows from the woodyard sump-dam and car rinse runoff on an intermittent and flow variable basis via Outfall 002. The facility is located approximately one mile south of Farm-to-Market Road 2246 and one mile southeast of the Town of Evadale, Jasper County, Texas 77615.

Federal register announcement (2010) announcement of Meadwestvaco Evadale kraft pulp and paper mill effluent discharge permit renewal.

Prior to the construction of the permanent saltwater barrier, temporary barriers were installed in the Lower Neches River during times of decreased flow . Studies observing the effects of these barriers on the quality of the river revealed decreased water quality below the barriers (Harrel 1975), particularly in sampling sites surrounding the effluent discharge. Harrel (1975) sampled the Neches River and determined that water quality deteriorated below the temporary saltwater barriers, as evidenced by low dissolved oxygen levels and macrobenthos abundance and diversity; water quality deteriorated the most during times of low flow (summer months). Seventeen years later, Harrel and Smith (2002) conducted a second study observing Neches River water quality following implementation of the Clean Water Act. Overall, results showed increased water quality in all areas of the river except those surrounding the effluent discharge. Sampling sites in this area revealed clear evidence of high concentrations of dissolved organic compounds (indicated by black water and low dissolved oxygen) and decreased macrobenthos species diversity relative to other sampling sites.

Intergovernmental Panel on Climate Change (IPCC) projections of global climate change do not bode well for the Texas coast. Climate change predictions and calculations for the Gulf Coast are generally for hotter and drier weather, increased periods of drought, rates of relative sea-level rise that are among the highest predicted in North America, and for an increase in the frequency and intensity of Tropical storms. These climate change effects are predicted to magnify some of the measured changes that have already been observed; namely sea-level rise and temperature increase. The effects are expected to be decreased freshwater flow to coastal wetlands and forests from decreased precipitation, decreased sediment deliveries leading to wetlands subsidence, higher sea-level elevation and inundation of freshwater marsh systems with sea water for longer periods, increased saltwater intrusion due to decreases in freshwater inflows, and increases in salinity.

Acceleration in sea-level rise will increase shoreline erosion in most regions (Brown and McLachlan 2002), with responses dependent upon sediment budgets (Stive et al. 2002, Cowell et al. 2003). Coastal vegetated wetlands are particularly sensitive to sea-level change. McFadden et al. (2007) estimated global losses of coastal wetlands from 2000 to 2080 at 33% with a 36 cm average rise in sea level, and 44% with a 72 cm average rise in sea level. Losses would be particularly great along the Atlantic and Gulf of Mexico coasts of North America (Donoghue 2011). Since the 1970s, at least half of the Gulf shoreline in Mississippi and Texas has eroded at rates averaging 2.6 to 3.1

m/yr, whereas 90%of the Louisiana shoreline has eroded at a rate of 12 m/yr (Morton et al. 2004).

The Lower Cypress tract is already subject to higher-than-natural salinity from human modifications to the environment, particularly from the Sabine-Neches waterway, a 40 foot-deep navigation channel from the Gulf of Mexico to the Port of Beaumont, less than 3 river miles away from the study area. Additional deepening of the channel to 48 feet, plus an increase in relative sea-level rise from global climate change and subsidence, may subject the study area to chronic, long-term periods of inundation and high salinity, effecting the productivity and survival of cypress-tupelo swamps. Large pulses of saltwater from tropical storms, which may be magnified due to changes in climate and the Sabine-Neches Waterway, may cause rapid and dramatic impacts. The combination of salinity and flooding stress has greater effects than either alone, and the negative impacts increase with increasing salinity.

Project Objectives

Given these potential impacts to the portion of the Beaumont Unit that lies downstream from the saltwater barrier, the objectives of this project were:

1. identification of focal species and habitats, and descriptions of their life histories, responses to salinity, and required environmental flow components;

2. field research in support of development of an environmental flow regime that best approximates the key functional components of the historic regime and that maintains optimal salinity and wetlands health, and persistence of freshwater wetlands within the area; and

3. recommendation of monitoring strategies that can measure the effectiveness of freshwater flows for protection of native species and habitats, and as mitigation of the predicted effects of climate change.

To accomplish the first objective, fish assemblages were surveyed within lower Neches River and bayous of the southern portion of the Beaumont Unit (hereafter referred to as the ‘study area’), and information about species tolerances of salinity and reduced water quality (e.g., low dissolved oxygen) was evaluated. This report also examines and compares the spatiotemporal variation of water quality and fish assemblages throughout the fall of 2011 (during the later stages of a record annual drought) and summer of 2012 (following a break in the drought that occurred during winter 2011-2012). Survey sites above and below the Neches saltwater barrier were compared in order to determine whether reduction of freshwater flows below the barrier results in higher salinity levels, accumulation of dissolved organic material from paper mill effluent, and changes in the diversity and composition of fish assemblages. Significant and prolonged increase in salinity was expected to cause an increase abundance of saltwater-tolerant freshwater fishes and estuarine/marine fishes, and also pose a threat to survival and recruitment of bald cypress and water tupelo trees emergent from surface waters. We therefore performed cursory, qualitative surveys for evidence of dead cypress and tupelo trees along shorelines during summer 2012 (after the 2011 drought). Research on vegetation dynamics is being conducted by other groups in collaboration with the Big Thicket Nature Preserve, however findings on tree mortality were not available when this report was prepared.

To develop an environmental flow regime that provides magnitudes and frequencies of key hydrologic components to maintain native wetland communities and aquatic biodiversity (Arthington 2012), water quality and fish assemblage information was used to estimate an environmental flow regime for the lower Neches River, a region not examined by the SB3 basin committees (Sabine/Neches BBEST 2009) or TCEQ (TCEQ 2011). A model was used to derive critical environmental flow components based on hydrologic data extrapolated from long-term records from three contributing upstream gages. Finally, recommendations are made for monitoring strategies and methods to gage the effectiveness of the environmental flow regime in relation to current and future anthropogenic impacts and predicted effects of climate change.

Methods

Field Surveys

Measurements of water quality parameters and fish samples were taken along the lower Neches River at localities above and below the saltwater barrier from

October–December 2011 and from May– August 2012 (Figures 2 and 3). Each water quality, seine, and gillnet sample site was sampled once per month during both periods (Tables 1 and 2). Water quality and gillnet samples were collected between 0700-1000 h, and seine samples were taken between 1000-1200 h. Sites were surveyed in sloughs of the southern portion of the Beaumont Unit and adjacent river channel in the reach below the saltwater barrier. Sites were selected to facilitate sampling (e.g., wadeable areas of river, availability of anchoring structures for gillnets).

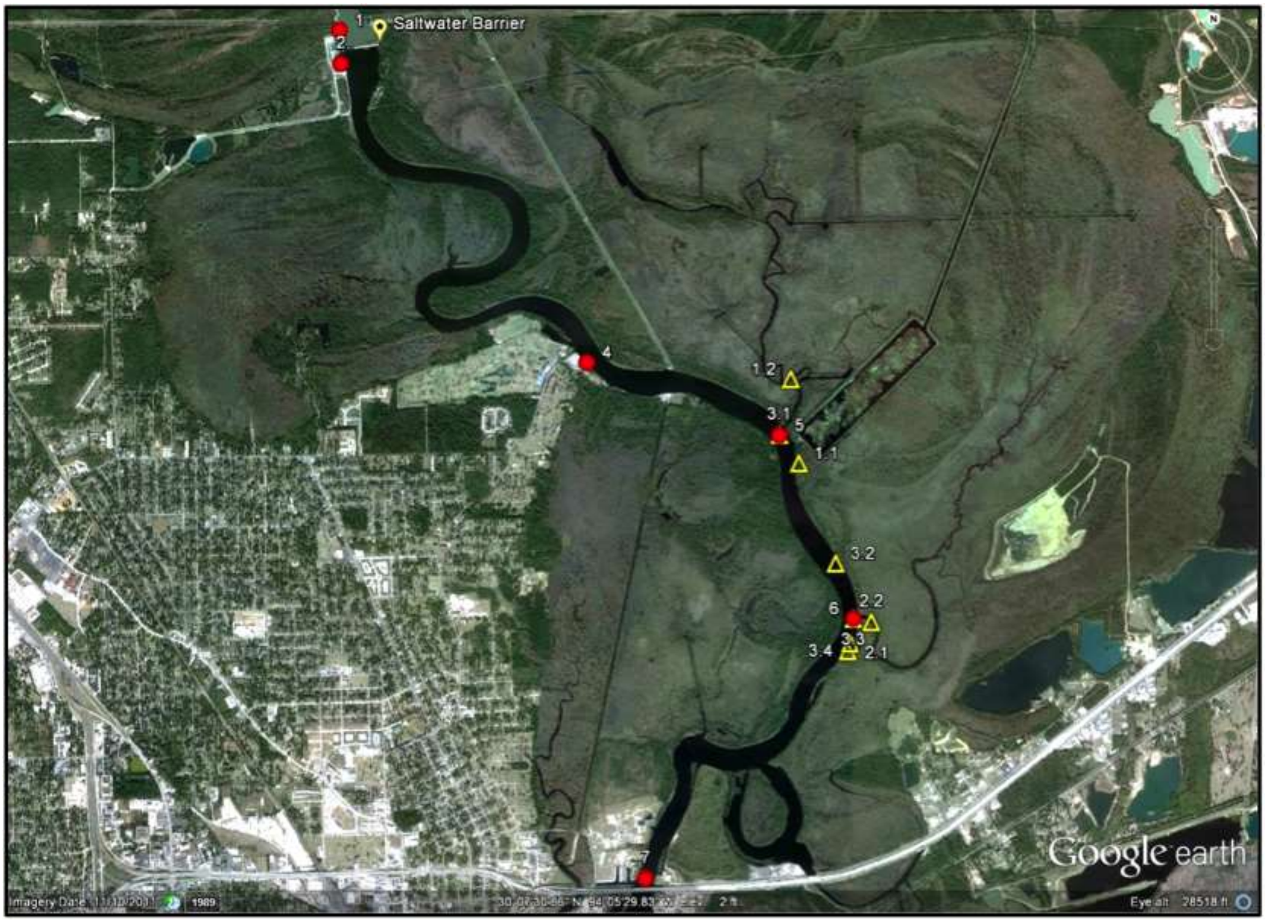

Figure 2. Water quality (circles) and gillnet sample sites (triangles; series 1: December, series 2: November, Series 3: December) during fall 2011. Differences in water color above the saltwater barrier, below the saltwater barrier, and within the MeadWestvaco paper mill effluent delivery canal and rectangular collecting pond witin the Beaumont Unit are apparent in this Google Earth image taken on November 10, 2011.

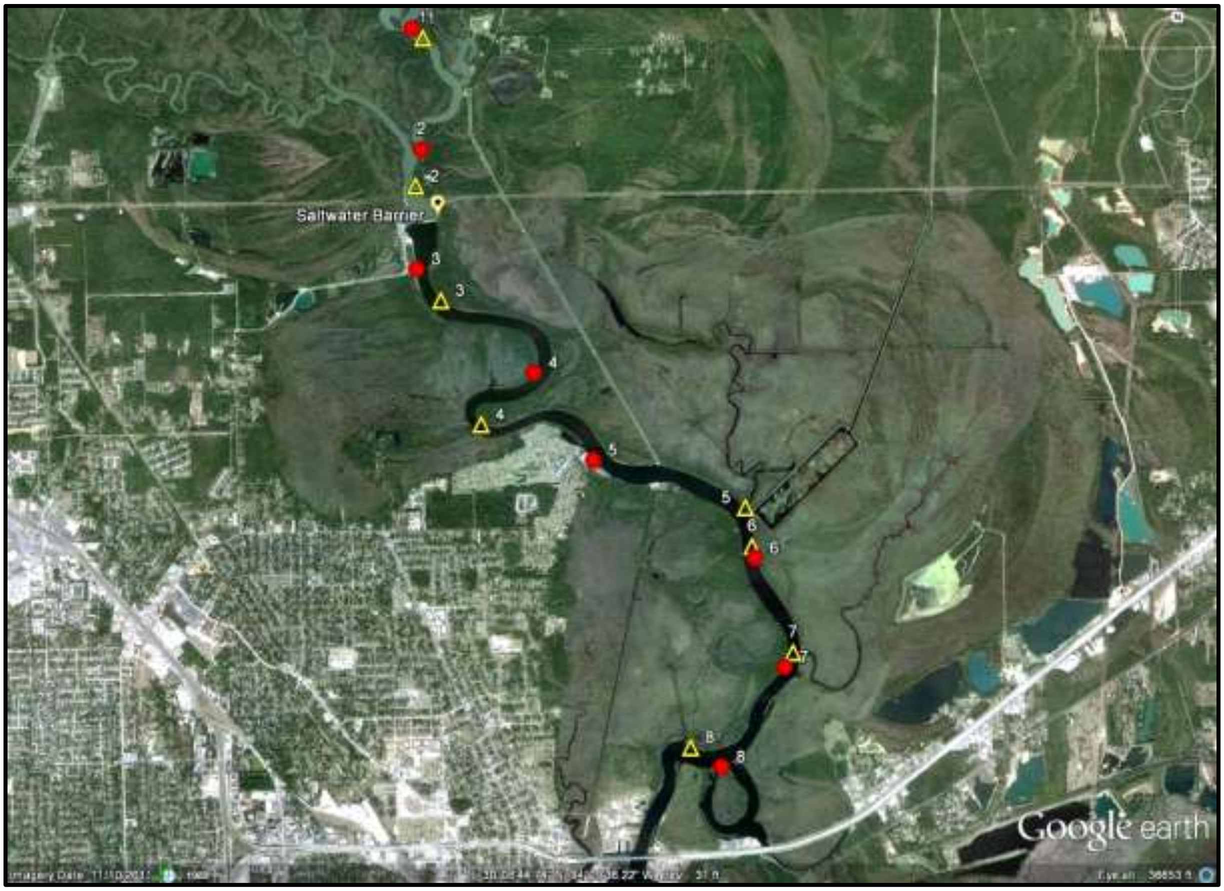

Figure 3. Seine (circles) and gillnet and water quality sites (both represented by triangles) during summer 2012. Again, water color differences above and below the saltwater barrier are apparent in this Google Earth image.

Water Quality

To characterize water quality along the river gradient, pH was measured using a handheld digital pH meter, and measurements of temperature (ºC), dissolved oxygen concentration (DO, mg/L), salinity (ppt), and conductivity (µs) were measured at each sampling locality using a Yellow Springs Instruments (YSI) model 85 meter and probe.

Fish Surveys

Fishes were surveyed along the river and within bayous using experimental gillnets. A 36.6-m x 1.8-m (4 panels: 1.3, 2.5, 5.1, and 7.6-cm bar mesh), two 9.8-m x 1.8-m (4 panels: 2.5, 5.1, 7.6, and 8.9-cm bar mesh), two 9.8-m x 0.9-m (4 panels: 1.3-, 2.5-, 5.1-, and 7.6-cm bar mesh), and two 38.1-m x 2.4-m (5 panels: 1.3, 2.5, 5.1, 7.6, and 8.9-cm bar mesh) monofilament experimental gillnets were used in various combination during fall 2011 and four 38.1-m x 2.4-m gillnets (5 panels: 1.3, 2.5, 5.1, 7.6, and 8.9-cm bar mesh) were deployed at each site during summer 2012. Gillnets were deployed at approximately 1700 h and retrieved at approximately 0800 h the following day. Data were standardized using CPUE (number of individuals or species per hour of deployment per 10-m of gillnet) due to variation in deployment time and gillnet size.

Gillnet sampling. Gillnets target large fishes including blue catfish (*Ictalurus furcatus*), smallmouth buffalo (*Ictiobus bubalus*) (top left), longnose gar (*Lepisosteus osseus*, top right), and redfish (*Sciaenops ocellatus,* bottom right).

A 1.8-m x 4.6-m seine (0.3 cm mesh) was used during 2011 and a 3-m x 6-m seine (0.3 cm mesh) was used during summer 2012 to sample fishes in shallow areas. During fall 2011, data were recorded and percent relative abundance was calculated for each locality. During summer 2012, multiple contiguous seine hauls were performed at each locality, and the distance of each seine haul was estimated in meters. The number of seine hauls and total distance of hauls per site depended on the area accessible for seining; to account for variation in seining effort, data were standardized using CPUE (number of individual fish or species obtained per meter of seine haul). Larger individuals obtained through either method were identified in the field and released; small- and medium-sized individuals were anesthetized using tricaine methanesulfonate (MS-222), preserved in 10% formalin, and later transferred to 70% ethanol. Preserved specimens were sorted and identified to species (or, in the case of small immature fishes, the lowest feasible taxonomic unit possible) in the laboratory.

Seine sampling. Top: a large seine was used in open areas within the Neches River channel. Bottom: a smaller seine was used in shallow areas within bayous.

Table 1. Sampling dates for each water quality, seine, and gillnet sample taken during fall 2011.

	Sample	Sample Date
Seine	October Seine 1	October 10, 2011
	October Seine 2	October 11, 2011
	October Seine 3	October 11, 2011
	November Seine	November 12, 2011
Gillnet	October	October 10, 2011
	October	October 10, 2011
	November	November 14, 2011
	November	November 14, 2011
	December	December 12, 2011
	December	December 12, 2011
	December	December 12, 2011
	December	December 12, 2011
Water Quality	November Site 1	November 14, 2011
	November Site 2	November 14, 2011
	November Site 4	November 14, 2011
	November Site 5	November 14, 2011
	November Site 6	November 14, 2011
	November Site 7	November 14, 2011
	December Site 1	December 12, 2011
	December Site 2	December 12, 2011
	December Site 4	December 12, 2011
	December Site 5	December 12, 2011
	December Site 6	December 12, 2011
	December Site 7	December 12, 2011

Table 2. Sampling dates for each water quality, seine, and gillnet sample taken during summer 2012.

	Site	Gillnet	Water Quality	Seine
May	1	May 16, 2012	May 16, 2012	May 16, 2012
	2	May 16, 2012	May 16, 2012	May 16, 2012
	3	May 17, 2012	May 17, 2012	May 17, 2012
	4	May 17, 2012	May 17, 2012	May 17, 2012
	5	May 18, 2012	May 18, 2012	May 17, 2012
	6	May 18, 2012	May 18, 2012	May 18, 2012
	7	May 19, 2012	May 19, 2012	May 18, 2012
	8	May 19, 2012	May 19, 2012	May 19, 2012
June	1	June 20, 2012	June 20, 2012	June 20, 2012
	2	June 20, 2012	June 20, 2012	June 20, 2012
	3	June 21, 2012	June 21, 2012	June 21, 2012
	4	June 21, 2012	June 21, 2012	June 21, 2012
	5	June 23, 2012	June 23, 2012	June 21, 2012
	6	June 23, 2012	June 23, 2012	June 23, 2012
	7	June 22, 2012	June 22, 2012	June 22, 2012
	8	June 22, 2012	June 22, 2012	June 22, 2012
July	1	July 18, 2012	July 19, 2012	July 19, 2012
	2	July 18, 2012	July 19, 2012	July 19, 2012
	3	July 20, 2012	July 20, 2012	July 19, 2012
	4	July 20, 2012	July 20, 2012	July 19, 2012
	5	July 21, 2012	July 22, 2012	July 20, 2012
	6	July 21, 2012	July 22, 2012	July 20, 2012
	7	July 22, 2012	July 22, 2012	July 21, 2012
	8	July 22, 2012	July 22, 2012	July 21, 2012
August	1	August 22, 2012	August 22, 2012	August 22, 2012
	2	August 22, 2012	August 22, 2012	August 22, 2012
	3	August 23, 2012	August 23, 2012	August 23, 2012
	4	August 23, 2012	August 23, 2012	August 23, 2012
	5	August 24, 2012	August 24, 2012	August 24, 2012
	6	August 24, 2012	August 24, 2012	August 24, 2012
	7	August 25, 2012	August 25, 2012	August 24, 2012
	8	August 25, 2012	August 25, 2012	August 25, 2012

Analysis of Species Assemblage Structure

For each sampling locality, species richness (calculated as the total number of species per 10 m of habitat seined for seine samples and as the number of species per 10 m of gillnet per h of deployment for gillnet samples), abundance catch-per-unit-effort (CPUE) of each species (calculated as the number of individuals collected per 10 m of habitat seined for seine samples and as the number of individuals per 10 m of gillnet per h of deployment for gillnet samples), and relative abundances (% of total number of individuals) were calculated for seine and gill net samples separately. Analysis of variance (ANOVA) was used to test for significant differences in abundance CPUE and species richness between samples obtained above and below the saltwater barrier, between individual sampling events, and between samples obtained when the barrier was closed and when it was open. Nonmetric multidimensional scaling (NMDS) analysis based on Bray-Curtis distances was used to characterize the relationship between species assemblage structure above and below the saltwater barrier based on abundance CPUE. Associations between species CPUE and environmental variables were examined using Canonical Correspondence Analysis (CCA). Prior to performing ANOVA, NMDS and CCA, the raw data were log(n + 1) transformed to make data distributions more closely approximate normal distributions. Statistical analysis was carried out using PAST and PC-ORD (McCune et al. 2002, Hammer 2011).

Indicator Fish Species

A list was compiled of the fish species collected during the 2011-2012 field surveys within the study area, and these species were evaluated for tolerance to salinity and aquatic hypoxia (low dissolved oxygen concentrations) based on a survey of literature. Particularly useful for categorization of Texas freshwater and estuarine fishes for tolerance of low dissolved oxygen was the report produced by the Texas Parks and Wildlife Department (Linam and Kleinsasser 1998) that was based on an extensive survey of fishery biologists in Texas. Evidence of salt tolerance by freshwater species was obtained from reports of fish surveys in coastal regions of the Gulf of Mexico, particularly the coastal regions of Texas, Louisiana, and Mississippi (Peterson and Ross 1991, Peterson and Meador 1994, Rozas et al. 1998, Gelwick et al. 2001, Akin et al. 2003). We also evaluated these indicator species based on recommendations for suitability as fluvial focal species based on life history attributes sensitive to variation in river flow. With respect to this latter aspect, a report that summarizes findings from a literature survey of candidate species for the Sabine and Neches River basins was prepared for the Sabine-Neches Bay and Basin Expert Science Team (Bio-West 2009).

The Texas SB3 Science-based Approach for Estimating Environmental Flow Regimes

An environmental flow regime for the lower Neches River (below the Saltwater Barrier) was estimated based on the science approach adopted under Texas Senate Bill 3 (SB3) and using available data and findings for the study area, including results from the analysis of water quality parameters, fish assemblages, and mortality of wetland trees. Information about the ecology of the indicator fish species from other study locations also provided useful guidance for assessing the flow needs.

SB3, passed in 2007, established an aggressive schedule for determining environmental flow standards adequate to support a sound ecological environment in all of the state’s river basins and bay systems. SB3 set out a new regulatory approach to protect environmental flows through the use of environmental flow standards developed through a local stakeholder process culminating in Texas Commission on Environmental Quality (TCEQ) rulemaking. SB3 defined as “an environmental flow regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats”. The SB3 schedule did not allow for the development of multi-year site-specific instream flow studies. Instead, SB3 required that environmental flow standards be predicated upon the best science and data currently available.

The magnitude of streamflow and its variation determine the characteristics of any riverine ecosystem. Where data are insufficient to establish relationships between streamflow and biological response, the historical streamflow data themselves can provide a meaningful basis for establishing, as a first approximation, environmental flow recommendations that are considered protective of current conditions. These initial recommendations must be subjected to refinement and adjustment based on available biological data and other information to better reflect actual ecosystem needs. To aid the scientists, stakeholders, regulators, and policymakers involved in SB3, a tool called the Hydrology-based Environmental Flow Regime (HEFR) was developed by the state's natural resource agency (Texas Parks and Wildlife Department) with input from other agencies and organizations. HEFR is a relatively flexible, statistical approach for developing a flow regime matrix that identifies multiple flow regime components of various levels across different months, seasons, or years. HEFR was used by all seven of the SB3 basin and bay science teams as they developed environmental flow regime recommendations.

HEFR produces summary statistics of flow regime components: subsistence flows, base flows, and high flow pulses (Table 3). Generally, either the Environmental Flow Components (EFC) method or the Modified Base Flow Index with Threshold (MBFIT) method (both implemented in a Microsoft Excel™ spreadsheet) is used to parse a hydrologic record into separate flow regime components. Excel is then used to efficiently develop summary statistics of these flow regime components. The HEFR methodology has several advantages, including: (1) it is computationally efficient, allowing for repeated tests and exploratory analyses, (2) there is significant flexibility in setting parameters to parse the hydrograph as well as summary statistics of the flow regime components, and (3) it provides an initial set of recommendations that reflect key aspects of the natural flow regime, including multiple flow components and hydrologic conditions.

Changes in a flow regime can be expected to produce changes in water quality conditions. The challenge is to ensure that the recommended flow regime protects water quality, particularly during low, or subsistence, flow conditions. The time limitation and inability to conduct site-specific field studies during the SB3 process meant that evaluation of biological factors in the development of environmental flow recommendations had to be efficient and relatively generalized. Below is an outline of essential steps for ecological analysis (sometimes referred to as "biological overlays") in developing environmental flow recommendations under SB3.

Table 3. Instream flow regime components and their definitions.

Component	Definition
Overbank flows	Represent s infrequent, high flow events that exceed the normal channel. These flows maintain riparian areas and lateral connectivity between the river channel and active floodplain. They may provide life-cycle cues for several species.
High flow pulses	Represents short-duration, in channel, high flows event following storm events. These flows maintain riparian areas and provide lateral connectivity between river channel and active floodplain. They may provide life-cycle cues for several species.
Base flows	Represents normal flow conditions, between precipitation events. They provide a range of suitable habitat conditions that support the natural biological community of a specific river sub-basin.
Subsistence flows	Represents infrequent, naturally occurring low flow events that occur for a seasonal period of time. They maintain sufficient water quality and provide sufficient habitat to ensure organisms populations capable of recolonizing the river systems once normal, base flow return.

Source: Sabine/Neches BBEST 2009

The initial step in the SB3 process was to establish operational objectives for support of "a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies". Operational objectives are: (1) maintain native biodiversity to the extent that is reasonable under recent conditions of climate, major infrastructure developments, and biological invasions; (2) maintain environmental quality and ecosystem productivity in support of this biodiversity and the recreational, commercial, and aesthetic uses of the renewable natural resources that it provides; and (3) maintain both short-term and long-term dynamics of habitats that support native biodiversity.

The next step is to compile and evaluate readily available biological information, especially for important species within the basin. A suitable set of indicator species should be identified that, when their ecological requirements are met, provide broad protection for most of the biological components of the ecosystem. When reviewing and summarizing studies and findings for the basin, certain kinds of biological and other ecological information desired for the analysis may be lacking. In such instances, options include use of biological data from adjacent river systems, making inferences based on life history information from the literature, and reliance on general habitat suitability criteria developed for species from multiple regions. The geographic distribution of identified river types should be estimated. Such data may include species distribution throughout the basin or portions thereof, the geographic range of state and federally listed threatened or endangered fish species and species of concern, location of any critical habitat or sensitive areas.

Biological information is used to inform the parameterization of HEFR (or other hydrologic methods), and the underlying decision points needed to produce a flow regime matrix. Some decisions should occur prior to generation of the flow regime matrix (pre-processing). These include the period of record for the analysis, the number of instream flow components and choice of hydrographic separation method. Once pre-processing decisions are made, decision points for modification of default parameters for both the hydrographic separation method and the HEFR analysis can be accomplished with available biological data in order to generate a flow regime matrix.

The initial flow regime matrix produced by HEFR analysis should be evaluated to ensure that the components of the biological system and their water quality and habitat requirements are maintained. Relationships between water quality parameters and subsistence flow should be evaluated and HEFR-derived subsistence flow values adjusted to ensure water quality parameters (e.g. DO) are maintained in a suitable range to ensure aquatic life persists/endures.

Base flows provide suitable and diverse habitat conditions and support the survival, growth, and reproduction of aquatic organisms. Information on indicator or key species can be used to validate and refine base flow estimates derived from HEFR analysis. A variety of tools can be used to evaluate suitable habitat. Incremental methods that relate habitat quality, quantity, and diversity to streamflow may be available for some rivers. Where cross-sections and rating curves are available hydraulic rating methods can be used to relate habitat-flow relationships. Qualitative life history information and conceptual models of indicator species' life cycles also can be used.

High flow pulses have important roles in maintaining water quality, physical processes, aquatic habitat connectivity, and a variety of roles in the ecology of aquatic and riparian species. Because they usually represent the greatest volume of water passing downstream on an annual basis, high flow pulses also tend to be the flow components targeted for storage and diversion for human uses. Pulse characteristics (such as the magnitude, timing, duration, and frequency) derived from the HEFR analysis should be evaluated and refined relative to life history information for focal species.

Hydrology-based Environmental Flow Regime (HEFR) Analysis

Hydrological data used for analyses to evaluate environmental flow needs were obtained from USGS gages: USGS 08041780 Neches River Saltwater Barrier at Beaumont; USGS 08041000 Neches River at Evadale; USGS 08041700 Pine Island Bayou near Sour Lake; and USGS 08041500 Village Creek near Kountze). The shortest period of record was for the Pine Island Bayou gage – 1968 to present. For the period 1968 to 2003 there are no flow data from the Saltwater Barrier gage. To fill this gap in order to extrapolate a longer flow record for hydrologic analysis for the Saltwater Barrier gage, the flows recorded upstream at Evadale, Village Creek, and Pine Island Bayou, were summed. 92% of the total flow measured at the Saltwater Barrier for years for which there are flow data is accounted for by the sum of the 3 upstream gages. Therefore, for each day of the earlier years, the sum of flows from the three upstream gages was divided by 0.92 in order to account for additional local inflows above the saltwater barrier. This adjustment gives a conservative estimate of the flows at the Saltwater Barrier, because it was calculated based on the 2004-present data, which includes diversions and gate closures. The 2004-2011 gage data from the Saltwater Barrier had some negative values that reflect upstream diversions and closure of the gates during times of low flow. The lowest flows recorded for Evadale all exceed 300 cfs. Therefore, if a value recorded at the Saltwater Barrier gage in recent times was <300 cfs, that recording was replaced with the value calculated from the same method employed for the pre-gage period. This eliminated negative values, extreme low values, and should provide data more reflective of the natural flow regime. Again, these calculations should be considered conservative, and actual flow values at this site, in the absence of diversions for the city of Beaumont and closure of the Saltwater Barrier gates, probably would have been slightly higher. Hydrology data and calculations are provided in Appendix 1.

The hydrologic flow component separation was performed in using the MBFIT option (see Appendix 2). Input parameters for MBFIT and HEFR were selected to match the inputs used by the Sabine/Neches BBEST for the key decision points for seasons (winter, spring, summer, fall), annual conditions (dry years [25th percentile], average years [50th percentile], wet years 75th percentile]), and number of high-flow pulse tiers based on frequency of occurrence (2 per season, 1 per season, 1 per year, 1 per 2 years). MBFIT parameter values were as follows: N = 11, f = 0.9, runoff fraction = 0.2, high flow upper threshold magnitude = 11700, high flow lower threshold magnitude = 2938, extreme low flow magnitude = 0.1, small flood magnitude = 1.5, and large flood magnitude = 99.99. Inputs for generating the flow regime table in HEFR were as follows: multipeaks_multiplier = ‘default’, water quality protection flow = 0, subsistence flows percentile = 0.05, winter starting month = January, and three seasons were designated (Jan–Mar, Apr–May–June, July–Sept, Oct–Dec). Bankfull discharge was extrapolated based on National Weather Service values published for bankfull stages for the Neches River at Evadale, Pine Island Bayou near Sour Lake, and Village Creek at Kounze. The sum of those values was divided by 0.92, which yielded an estimate of bankfull discharge at the Saltwater Barrier of 13043 cfs. Complete HEFR input data and calculations are provided in Appendix 3.

To evaluate and modify the HEFR-derived flow regime components for the Saltwater Barrier gage, the approach and relevant sources of evidence produced by the Sabine/Neches BBEST were used in conjunction with evidence obtained from the 2011–2012 field research in the study area. Environmental flow recommendations from the Sabine/Neches BBEST Biological Overlay (2009) and Sabine/Neches BBEST Environmental Flows Recommendation Report (2009) for two upstream gages included in that analysis (Village Creek, Evadale) were evaluated together with analysis of water quality, focal fish species, fish assemblage, and evidence of mortality among bald cypress and water tupelo trees along the shoreline of area waterways. In addition, salinity model findings from US Army Corps of Engineers (USACE 2006/2007) were reviewed in the context of the environmental flow regime derived from HEFR and biological overlay analysis.

The definition for environmental flows that sustain a sound ecological environment proposed by the state Science Advisory Committee was adopted: a flow regime that (i) sustains the full complement of native species in perpetuity, (ii) sustains key habitat features required by these species, (iii) retains key features of the natural flow regime required by these species to complete their life cycles, and (iv) sustains key ecosystem processes and services, such as elemental cycling and the productivity of important plant and animal populations.

The life history requirements of focal species was reviewed in the context of the HEFR flow regime matrix in order to determine if any critical components were lacking, and also whether or not any flow regime components were unnecessarily redundant in light of current implementation rules for environmental flows under

SB3. Analyses of high flow pulses with respect to riparian wetland vegetation communities performed by the National Wildlife Federation (NWF) and Greater Edwards Aquifer Alliance (GEAA) (Sabine/Neches BBEST 2010, Appendix 9.3.2) were evaluated with respect to the high flow pulses derived from HEFR. Because no analysis had been performed for riparian areas of the lower Neches River, the assumption was made that the flow tier categories (same categories but with flow values calculated for the Saltwater Barrier gage) that produced riparian inundation at the Evadale site would also inundate riparian areas in the lower Neches.

During subsistence flow conditions, larger fishes (e.g., channel and blue catfish, smallmouth buffalo, blue sucker, gars, freshwater drum, largemouth and spotted bass) refuge in the deeper and larger pools of the main channel and side channels. Sloughs may support populations of gars, bass, crappies, sunfishes, and small fishes (e.g., pugnose minnow, blackstripe top minnow). Few site-specific studies have been performed in the Sabine and Neches river basins to inform recommendations about availability of suitable habitat during subsistence and base flows. Werner (1982) performed an analysis of hydraulic habitat in the Neches River. He employed the Physical Habitat Simulation (PHABSIM) component of the Instream Flow Incremental Methodology (Bovee and Milhous 1978) to estimate habitat available for life stages of focal fish species under a range of discharge levels. Werner relied on literature-based suitability curves rather than developing site-specific indices. By weighting the results to reflect the needs of the most habitat-restricted life stages and species, he derived recommended monthly maintenance flows and flows during drought conditions for two segments of the river located upstream from the study area. Werner's findings are valuable for comparison with our flow value ranges for subsistence and dry-year base flows, respectively, and for examination of estimates of weighted usable habitat area for various species under different flow levels. In addition, Werner provided recommended flows during periods of drought, and these would be equivalent to what we now refer to as subsistence flows. In general, Werner's recommendations for drought/maintenance flows are significantly higher than the values obtained by the Sabine/Neches BBEST for the Evadale gage located upstream from Werner's sites. Although no other specific instream flow studies have been completed in the basin, evaluation of biological/ecological responses to flow variation was assisted by information summarized by Bio-West for the Sabine/Neches BBEST (Bio-West 2009).

The magnitude and duration of high flow pulses can also be checked with known fish life history requirements. High flow pulses provide environmental cues that elicit reproductive behavior (migration, spawning), produce lateral connectivity allowing movement of fish between the main channel and off-channel aquatic habitats (floodplain lakes, oxbows, sloughs, ephemeral ponds), and foraging opportunities in newly flooded riparian habitats. Evaluation of the benefits of high flow pulses should focus on the timing and duration of the pulse in relation to the requirements for spawning cues, feeding opportunities of juveniles, etc., and the interaction between lateral connectivity and habitat availability.

For white bass, high flow pulses cue and enhance spawning migrations during early spring. High flow pulses during spring are most beneficial for spotted bass and other sunfishes when they have a duration of 3 weeks, because this provides these fishes sufficient time to construct a nest, spawn, and guard the eggs and lavae until they are large enough to swim effectively. The shoal chub, ghost shiner and emerald shiner are minnows characteristic of large rivers. Shoal chubs and ghost shiners require broad sandbanks for foraging; the availability of submerged bank habitats increases during high flows, and high flows transport eggs/larvae of these broadcast spawners. Responses to flow pulses by populations of the dusky darter, would likely be similar to the nest/guarding bass and sunfishes, except the darter nests in shoals and riffles with rough substrates rather than littoral areas with low flow.

Overbanking flows are important for moving coarse woody debris and sediments, scouring deep pools and depositing sediments to form sandbanks, and allowing aquatic organisms to colonize ephemeral aquatic floodplain habitats. Inundation of floodplains allows seeds of bottomland hardwood tree species to disperse or germinate following flood subsidence. Bald cypress, water tupelo, and other bottomland hardwood tree species require periodic flooding for successful germination, seedling recruitment, and elimination of upland plant species that are competitively superior on well-drained soils (Sharitz and Mitsch 1993). Overbanking flows also maintain sediment dynamics and geomorphic changes of the landscape needed to maintain riparian forest diversity (Shankman 1993, Meitzen 2009).

In addition to supporting major geomorphic processes, overbank flows provide lateral connectivity for aquatic organisms to floodplain areas and maintain the balance and diversity of riparian zones. Most “overbanking flows” do not result in extensive inundation of floodplain terrains, but instead water moves into bottomland wetlands, first in the lowest areas, such as oxbows and sloughs, and moving into wetlands with slightly higher elevations as flows inch upward. This pattern of variable flooding with variable flows is a natural consequence of landscape heterogeneity in floodplains. The overbanking flow components of the HEFR derived flow matrix thus have important functions for the ecological system, and for some species this component is critical for completion of the life cycle (i.e., bottomland hardwood tree species).

Results

Neches River Hydrology During Study Period

Texas experienced extreme drought conditions during most of 2011 as evidenced by the flow patterns of the Neches River at the saltwater barrier (Figure 4). From late 2010 to late 2011, the Neches River exhibited a low, mostly consistent, flow with few large flow pulses. Two of the three fall sampling events in 2011 occurred during drought conditions, with a third sampling event occurring during December after a period of rainfall (Figure 5). From January 2012 until May 2012, drought conditions lessened and the Neches River exhibited more frequent high flow pulses. Daily mean discharge was relatively stable during summer 2012, with the exception of a large flow pulse during July (Figure 6). Average discharge during summer 2012 (3,425 cubic feet per second [cfs]) was significantly greater than discharge during fall 2011 (323.2 cfs) (ANOVA; $F_{1,195} = 44.45$; $P < 0.001$).

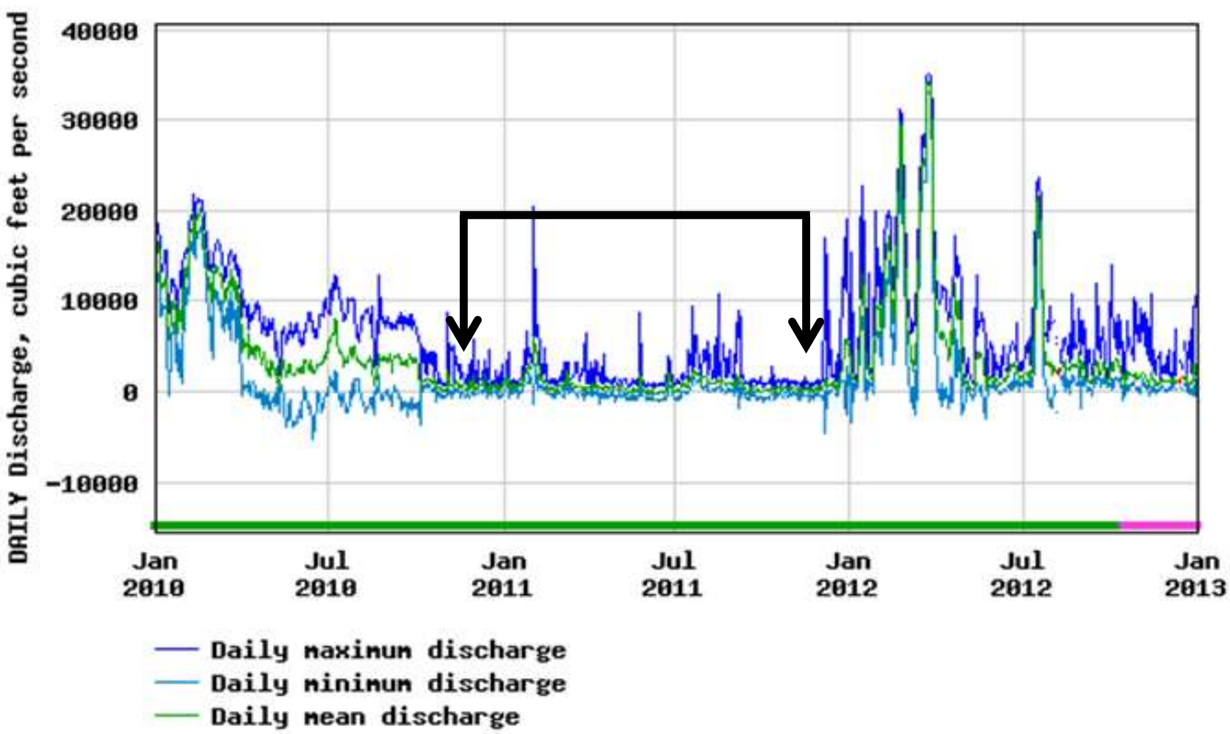

Figure 4. Daily maximum, minimum, and mean discharge rates (cubic feet per second) for the Neches River at the saltwater barrier near Beaumont, Texas from January 2010 to January 2013 (source: USGS 08041780). Period between black arrows represents flow patterns during the 2011 drought.

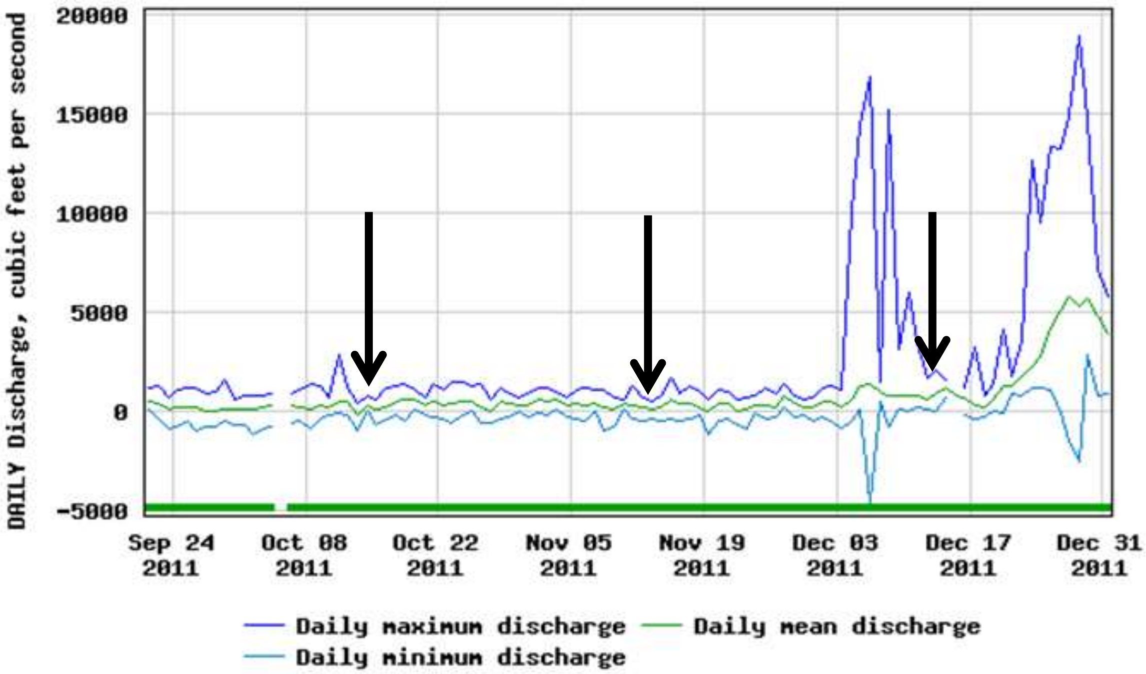

Figure 5. Daily maximum, minimum, and mean discharge rates (cfs) for the Neches River at the Saltwater Barrier near Beaumont from September–December 2011 (source: USGS 08041780). Black arrows represent sampling events. October and November's sampling dates occurred during the drought; December sampling occurred after a series of rain events.

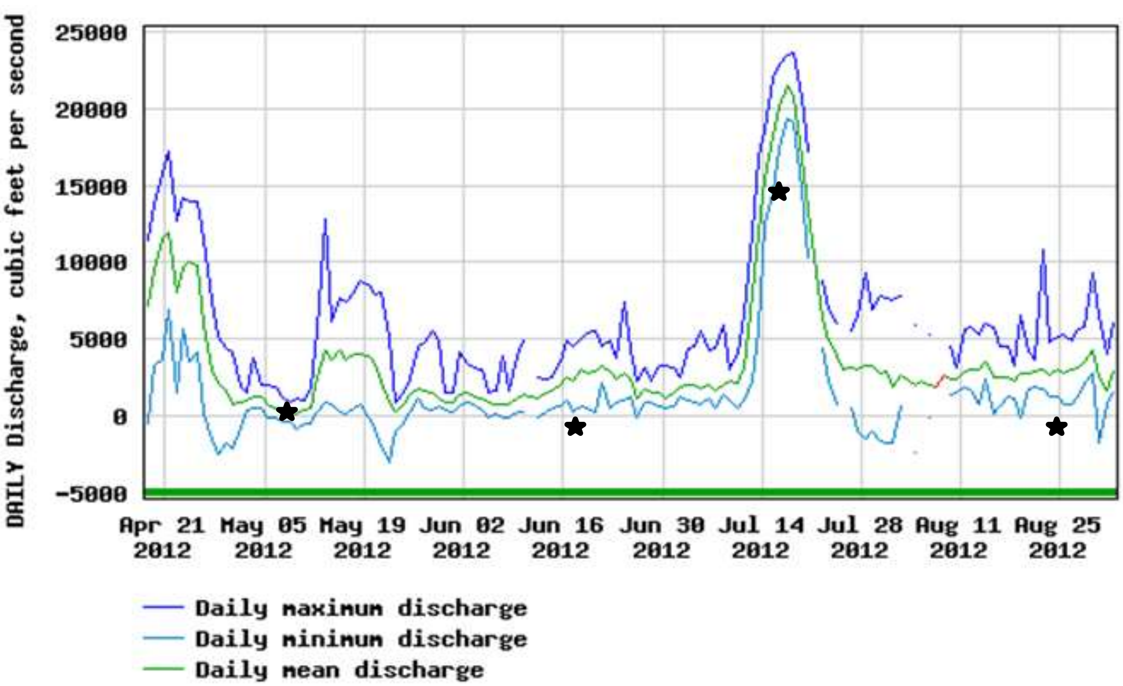

Figure 6. Daily maximum, minimum, and mean discharge rates (cfs) for the Neches River at the Saltwater Barrier near Beaumont from April–August 2012 (source: USGS 08041780). Stars indicate sampling events.

Fish Surveys – Gillnet Samples

Gillnet sampling during fall of 2011 yielded a total of 43 specimens (representing 12 species); 11 specimens in October, 2 specimens in November, and 30 specimens in December. Due to an error recording data in the field, one of the gillnet samples obtained during October 2011 could not be included in data analysis. Gillnet samples during the fall 2011 were dominated by *Ictalurus punctatus, Ictiobus bubalus,* and *Dorosoma petenense*. During summer 2012, a total of 489 specimens (representing 38 species) was collected from gillnets; 91 specimens in May (25 species), 188 specimens in June (25 species), 81 specimens in July (20 species), and 129 specimens in August (21 species). No species collected during summer 2012 were present during all

Spotted gar (*Lepisosteus oculatus),*10 Mile Bayou, November 2011.

Longnose gars (*Lepisosteus osseus)* and gizzard shad (*Dorosoma cepedianum*), lower Neches River, May 2012.

Southern flounder (*Paralichthys lethostigma)*, lower Neches River, July 2012.

months (Table 5). During summer 2012, gillnet samples were dominated by *Lepisosteus* spp., *I. bubalus, Ictalurus furcatus,* and *Dorosoma cepedianum.* Twelve of the 38 species obtained through gillnet surveys during the summer 2012 were only found during one sampling month, whereas nine species were present during all months (Table 5).

Fish Surveys – Seine Samples

Seine sampling during fall 2011 was conducted with the objective of the relative abundances of small fishes. A total of 789 specimens (representing 15 species) was collected with seines; 557 specimens (10 species) were collected during October and 232 specimens (8 species, Table 4) were collected during November. Samples were dominated by the estuarine species *Anchoa mitchilli, Cyprinodon variegatus,* and *Menidia beryllina.* Based on the results from qualitative surveys during fall 2011, seine sampling during fall 2012 was conducted in a standardization manner to allow for quantitative comparisons of species richness and abundance CPUE among locations and sampling periods. In 2012, a total of 27,180 specimens (representing 57 species) was collected with seines; 16,377 specimens (40 species) were collected during May, 3,611 specimens (27 species) were collected during June, 3,998 specimens (37 species) were collected during July, and 3,194 specimens (24 species) were collected during August. Seine samples were dominated by *A. mitchilli* and species of the families Cyprinidae, Clupeidae, and Centrarchidae. Eighteen species were captured during the four sampling months of 2012 (Table 5).

Table 4. Percent composition of species obtained from gillnet surveys each month during fall 2011. Dashes indicate no individuals of that species were obtained during that month. Boldface type designates indicator species.

Family	Species	October	November	December
Lepisosteidae	Longnose gar, *Lepisosteus osseus*	100.0%	-	-
Clupeidae	Gizzard shad, *Dorosoma cepedianum*	-	50.0%	-
	Gulf menhaden, *Dorosoma petenense*	-	-	13.3%
Catostomidae	**Smallmouth buffalo, *Ictiobus bubalus***	**-**	**-**	**20.0%**
Ictaluridae	Channel catfish*, Ictalurus puncatus*	-	-	40.0%
Mugilidae	Striped mullet, *Mugil Cephalus*	-	-	6.7%
Moronidae	Hybrid striped bass, *Morone saxatilis x chrysops*	-	-	3.3%
	Yellow Bass, *Morone mississippiensis*	-	-	3.3%
Centrarchidae	*Micropterus* spp.	-	-	3.3%
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*	-	-	6.7%
	Red drum, *Sciaenops occelatus*	-	-	3.3%
	Unidentified Sciaenidae	-	50.0%	-
	Total Number of Fish	1	2	30

Table 5. Abundance catch-per-unit-effort (CPUE) of each species (the number of individuals collected per 10-m of gillnet per h of deployment) obtained from gillnet sampling during summer 2012. Dashes indicate no individuals of the species were obtained during that month from that site. Boldface type designates indicator species.

Family	Species	Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Lepisosteidae	Alligator gar, *Atractosteus spatula*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	0.01	0.02	0.01	0.03
		July	-	-	-	0.02	0.01	-	-	-
		Aug	-	-	-	-	-	-	-	0.01
	Spotted gar, *Lepisosteus oculatus*	May	-	-	0.01	-	-	-	-	0.03
		June	0.01	0.06	0.03	0.03	0.01	0.07	0.09	0.02
		July	0.01	0.02	0.02	0.04	-	0.01	0.02	-
		Aug	-	-	0.01	0.01	-	0.02	-	-
	Longnose gar, *Lepisosteus osseus*	May	0.01	0.03	0.001	0.02	-	0.01	-	-
		June	0.01	0.12	0.01	0.02	-	0.03	0.01	-
		July	0.01	0.05	0.02	-	-	0.02	-	0.01
		Aug	-	0.01	0.02	0.01	-	-	-	0.02
Elopidae	Ladyfish, *Elops saurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	0.01	-	-	-	-	-
Clupeidae	Skipjack shad, *Alosa chrysochloris*	May	-	0.01	-	0.01	0.01	-	0.02	0.02
		June	0.02	0.02	-	0.01	-	-	-	-
		July	-	0.01	-	-	-	-	-	-
		Aug	-	-	0.05	0.01	-	-	-	0.01
	Gulf menhaden, *Brevoortia patronus*	May	-	-	-	-	0.01	-	-	0.18
		June	0.01	0.01	-	-	0.01	0.01	-	0.08
		July	-	-	-	-	-	-	-	-
		Aug	-	0.18	0.12	0.01	-	0.01	-	0.08
Moronidae	Yellow bass, *Morone missisippiensis*	May	-	-	-	-	-	-	-	0.01
		June	-	-	0.01	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Hybrid striped bass, *Morone saxatilis x chrysops*	May	-	-	-	-	-	-	-	0.01

Moronidae	Yellow bass, *Morone missisippiensis*	May	-	-	-	-	-	-	-	0.01
		June	-	-	0.01	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Yellow bass, *Morone missisippiensis*	May	-	-	-	-	-	-	-	0.01
		June	-	-	0.01	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Hybrid striped bass, *Morone saxatilis x chrysops*	May	-	-	-	-	-	-	-	0.01
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
Centrarchidae	**Flier, *Centrarchus macropterus***	**May**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**-**	**0.01**	**0.01**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**0.01**	**-**	**-**	**0.01**
	Warmouth, *Lepomis gulosus*	May	-	-	-	0.01	-	-	-	-
		June	-	-	-	-	-	-	0.01	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Bluegill, *Lepomis macrochirus*	May	0.01	0.01	-	-	-	-	0.01	-
		June	-	-	0.02	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	0.02	-	-	0.01	-
	Longear sunfish, *Lepomis megalotis*	**May**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**0.01**	**-**
		July	**-**	**-**	**-**	**-**	**0.03**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Redear sunfish, *Lepomis microlophus*	May	-	-	0.01	0.01	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.06	0.01	-	-
		Aug	-	-	-	-	-	-	-	-
	Spotted bass,	**May**	**-**	**-**	**0.01**	**-**	**-**	**-**	**-**	**-**

	Micropterus punctulatus									
		June	**-**	**-**	**-**	**0.01**	**0.01**	**-**	**-**	**0.02**
		July	**-**	**-**	**-**	**-**	**0.01**	**-**	**-**	**0.01**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Largemouth bass, *Micropterus salmoides*	May	-	0.01	-	-	-	-	-	-
		June	-	-	0.04	0.02	-	0.02	-	-
		July	-	-	-	-	0.01	0.02	-	-
		Aug	-	-	-	-	-	-	-	-
	White crappie, *Pomoxis annularis*	**May**	**-**	**-**	**0.04**	**0.02**	**-**	**-**	**-**	**-**
		June	**0.01**	**-**	**0.01**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**-**	**0.01**	**0.02**	**-**	**0.01**	**-**	**-**
		Aug	**-**	**0.02**	**-**	**-**	**-**	**-**	**-**	**-**
Sparidae	Sheepshead, *Archosargus probatocephalus*	May	-	-	-	-	0.01	-	-	-
		June	-	-	-	0.01	-	-	0.01	0.01
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*	May	-	0.02	0.01	-	0.01	-	0.01	-
		June	0.01	0.01	0.01	0.01	-	0.01	0.02	-
		July	-	0.01	-	0.01	-	0.03	-	-
		Aug	0.03	-	0.01	-	-	-	-	-
	Sand seatrout, *Cynoscion arenarius*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	0.001	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Spot croaker, *Leiostomus xanthurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	0.04
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Atlantic croaker, *Micropogonias undulatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	0.01	-	0.01
	Red drum, *Sciaenops ocellatus*	May	-	-	-	-	0.01	-	0.01	0.01
		June	-	-	-	-	-	0.01	-	0.02
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	0.01

Eleotridae	Fat sleeper, *Dormitator maculatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.01	-
		Aug	-	-	-	-	-	-	-	-
Paralichthyidae	Bay whiff, *Citharichthys spilopterus*	May	-	-	0.01	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Southern flounder, *Paralichthys lethostigma*	May	-	-	-	-	-	-	-	-
		June	-	-	-	0.01	-	-	-	-
		July	-	-	-	-	-	-	-	0.03
		Aug	-	-	-	-	-	-	-	0.04
Achiridae	Hogchoker, *Trinectes maculatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	0.01	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-

Seine sample from the main channel of the lower Neches River, May 2012. Minnows, sunfishes, and a gar were among the species captured.

Table 6. Percent composition of species obtained from seine surveys during fall 2011 by month and site. Dashes indicate no individuals of that species were obtained in that sample. Boldface type designates indicator species.

Family	**Species**	**October Seine 1**	**October Seine 2**	**October Seine 3**	**November Seine 1**
Engraulidae	Bay anchovy, *Anchoa mitchilli*	16.00%	-	-	25.00%
Clupeidae	Gulf menhaden, *Brevoortia patronus*	10.00%	-	-	-
Mugilidae	Striped mullet, *Mugil cephalus*	1.00%	-	-	-
Atherinopsidae	Inland silverside, *Menidia beryllina*	72.00%	22.60%	6.10%	64.20%
Fundulidae	Bayou killifish, *Fundulus pulvereus*	-	3.80%	1.20%	-
	Fundulus species, unidentified	-	-	-	0.90%
	Gulf killifish, *Fundulus grandis*	-	-	-	3.00%
	Rainwater killifish, *Lucania parva*	-	-	2.90%	3.00%
Cyprinodontidae	Sheepshead minnow, *Cyprinodon variegatus*	-	62.70%	6.50%	-
Poeciliidae	Sailfin molly, *Poecilia latipinna*	-	9.40%	72.20%	-
	Western mosquitofish, *Gambusia affinis*	1.00%	1.40%	10.60%	-
Centrarchidae	*Lepomis* spp.	-	-	0.40%	-
Sciaenidae	Spot croaker, *Leiostomus xanthurus*	-	-	-	3.00%
	Unidentified Sciaenidae	-	-	-	0.40%
Gobiidae	*Ctenogobius* spp.	-	-	-	0.40%
	Total Number of Fish	**100**	**212**	**245**	**232**

Table 7. Abundance (CPUE) of each species (the number of individuals collected per 10-m of habitat seined) obtained from seine sampling during summer 2012. Dashes indicate no individuals of the species were obtained during that month from that site.

Family	**Species**	**Month**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
Elopidae	Ladyfish, *Elops saurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	0.03	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
Engrualidae	Bay anchovy, *Anchoa mitchilli*	May	2.36	10.45	15.50	108.85	10.60	11.67	70.77	69.05
		June	3.51	8.00	0.75	3.15	1.95	27.98	5.86	13.90
		July	0.02	-	25.47	13.50	21.32	2.07	3.64	4.10
		Aug	0.42	0.03	5.58	20.20	27.40	3.45	2.67	4.83
Cyprinidae	Red shiner, *Cyprinella lutrensis*	May	0.16	-	-	-	0.03	-	-	0.05

		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		August	-	-	0.11	-	-	-	-	-
	Blacktail shiner, *Cyprinella venusta*	May	10.77	4.00	0.33	0.20	1.30	0.02	0.17	3.00
		June	0.70	0.46	0.26	0.47	0.06	0.04	0.06	0.05
		July	0.11	0.37	-	-	0.03	-	0.20	1.60
		Aug	4.17	2.40	-	2.56	0.76	0.03	0.16	0.13
	Ribbon shiner, *Lythrurus fumeus*	May	0.08	0.42	0.03	-	-	-	-	-
		June	-	0.04	-	-	-	0.04	-	-
		July	0.05	0.08	0.47	-	-	-	0.07	0.40
		Aug	0.02	0.37	-	-	-	-	-	-
	Shoal chub, *Macrhybopsis hyostoma*	May	0.01	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Golden shiner, *Notemigonus crysoleucas*	May	-	-	-	-	-	-	-	-
		June								
		July	-	-	-	-	-	-	-	0.03
		Aug	-	-	-	-	-	-	-	-
Cyprinidae	Sabine shiner, *Notropis sabinae*	May	0.03	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Weed shiner, *Notropis texanus*	May	0.63	0.208	-	-	-	-	-	-
		June	0.30	-	0.075	-	-	-	-	-
		July	0.54	0.208	0.667	0.08	-	-	-	-
		Aug	1.86	1.733	0.244	0.68	-	-	-	-
	Mimic shiner, *Notropis volucellus*	May	2.96	3.042	-	-	-	-	-	-
		June	0.05	-	-	-	-	-	-	-
		July	1.20	1.42	-	-	-	-	-	-
		Aug	0.03	0.07	-	-	-	-	-	-
	Pugnose minnow, *Opsopoeodu*	May	-	-	-	-	-	-	-	-

	s emiliae									
		June	**0.22**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**0.03**	**-**	**-**	**0.03**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Bullhead minnow, *Pimephales vigilax*	**May**	**3.21**	**3.33**	**0.03**	**-**	**-**	**-**	**-**	**-**
		June	**1.25**	**0.75**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**3.23**	**2.38**	**0.07**	**0.05**	**-**	**-**	**-**	**-**
		Aug	**2.57**	**1.60**	**-**	**-**	**-**	**-**	**-**	**-**
Catostomidae	**Smallmouth buffalo, *Ictiobus bubalus***	**May**	**0.01**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Ictaluridae	Blue catfish, *Ictalurus furcatus*	May	0.01	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Channel catfish, *Ictalurus punctatus*	May	0.01	-	-	0.03	0.05	0.07	0.17	0.05
		June	-	-	-	-	0.03	-	-	-
		July	-	-	-	-	-	-	0.07	-
		Aug	-	-	-	-	-	-	-	-
Mugilidae	Striped mullet, *Mugil cephalus*	May	0.01	-	0.03	0.03	0.35	-	-	-
		June	-	-	-	-	-	0.02	-	-
		July	-	-	-	0.03	-	-	-	0.03
		Aug	-	-	-	-	-	-	0.22	0.20
Atherinopsidae	**Brook silverside, *Labidesthes sicculus***	**May**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**0.017**	**-**	**0.03**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**0.08**	**-**	**-**	**0.03**	**-**	**-**	**-**
		Aug	**0.03**	**-**	**-**	**-**	**0.03**	**-**	**-**	**-**
	Inland silverside, *Menidia beryllina*	May	-	0.08	0.30	1.48	1.93	0.98	2.03	3.80
		June	0.05	0.08	0.13	0.30	0.96	1.49	2.62	0.90
		July	-	0.04	-	0.10	3.80	4.91	2.27	6.27

		Aug	0.14	0.03	0.22	0.40	3.45	0.18	0.69	0.13
Belonidae	Atlantic needlefish, *Strongylura marina*	May	-	-	-	0.03	-	-	-	-
		June	-	0.04	-	-	-	0.02	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
Fundulidae	Gulf killifish, *Fundulus grandis*	May	-	-	-	-	0.58	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.08	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Blackstripe topminnow, *Fundulus notatus*	**May**	**0.01**	**0.04**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**0.057**	**0.417**	**-**	**0.025**	**-**	**0.022**	**-**	**-**
		Aug	**0.229**	**0.133**	**0.156**	**-**	**-**	**-**	**-**	**-**
Fundulidae	Rainwater killifish, *Lucania parva*	May	-	-	-	-	0.03	0.04	0.03	-
		June	-	-	-	-	-	-	-	0.03
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
Cyprinodontidae	Sheepshead minnow, *Cyprinodon variegatus*	May	-	-	-	-	0.03	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.10	-	0.02	-
		Aug	-	-	-	-	-	-	-	-
Poeciliidae	Western Mosquitofish, *Gambusia affinis*	May	-	0.21	0.13	0.03	-	0.09	0.31	0.85
		June	-	0.04	0.05	-	-	-	-	0.03
		July	-	0.25	-	0.03	-	0.09	9.27	0.80
		Aug	-	0.03	-	-	-	-	-	-
	Least killifish, *Heterandria formosa*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.07	-
		Aug	-	-	-	-	-	-	-	-
	Sailfin molly, *Poecilia*	May	-	-	-	-	-	0.02	-	0.05

	latipinna									
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.36	-
		Aug	-	-	-	-	-	-	-	-
Syngnathidae	Opossum pipefish, *Microphis brachyurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	0.04	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Gulf pipefish, *Syngnathus scovelli*	May	-	-	-	0.03	-	-	0.03	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	0.02	0.07	-
		Aug	-	-	-	-	-	-	-	-
Moronidae	**White bass, *Morone chrysops***	**May**	**-**	**-**	**0.03**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Centrarchidae	**Flier, *Centrarchus macropterus***	**May**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**0.03**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Green sunfish, *Lepomis cyanellus*	May	-	-	-	-	0.03	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Warmouth, *Lepomis gulosus*	May	-	0.04	0.07	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	0.07	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Bluegill, *Lepomis macrochirus*	May	0.05	0.21	0.03	-	-	-	-	-
		June	0.05	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	0.03	0.04	-	-	-	0.02	0.03
	Longear sunfish,	**May**	**-**	**1.17**	**0.03**	**0.05**	**-**	**-**	**-**	**-**

	Lepomis megalotis									
		June	**0.03**	**0.04**	**0.03**	**0.03**	**-**	**-**	**-**	**-**
		July	**0.06**	**1.08**	**-**	**-**	**-**	**0.33**	**0.56**	**-**
		Aug	**0.06**	**0.17**	**-**	**0.24**	**-**	**-**	**-**	**0.03**
	Redear sunfish, *Lepomis microlophus*	May	0.01	-	0.07	0.05	-	0.02	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Redspotted sunfish, *Lepomis miniatus*	**May**	**-**	**-**	**0.07**	**-**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Lepomis spp. (Juvenile sunfish)	May	-	-	-	-	-	-	-	-
		June	0.05	0.04	-	-	-	-	-	-
		July	-	-	0.13	-	-	-	-	0.03
		Aug	-	-	-	-	-	-	-	0.03
	Spotted bass, *Micropterus punctulatus*	**May**	**0.03**	**0.71**	**0.10**	**-**	**-**	**-**	**-**	**-**
		June	**0.03**	**0.20**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**0.06**	**0.08**	**0.13**	**-**	**-**	**0.07**	**-**	**-**
		Aug	**0.03**	**-**	**-**	**-**	**-**	**-**	**0.07**	**-**
	Largemouth bass, *Micropterus salmoides*	May	0.08	-	0.17	0.15	0.05	0.02	-	-
		June	0.02	-	-	-	-	-	0.02	-
		July	-	-	-	-	0.03	0.04	-	0.03
		Aug	-	-	0.02	-	-	-	-	0.03
	White crappie, *Pomoxis annularis*	**May**	**-**	**0.04**	**-**	**0.03**	**-**	**-**	**-**	**-**
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Percidae	**Bluntnose darter, *Etheostoma***	**May**	**0.01**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

	chlorosomum									
		June	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**0.04**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	Dusky darter, *Percina sciera*	**May**	**0.10**	**0.04**	**-**	**-**	**-**	**-**	**-**	**-**
		June	**0.02**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
		July	**0.03**	**0.08**	**-**	**-**	**-**	**-**	**-**	**-**
		Aug	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*	May	0.09	0.04	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	0.17	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Sand seatrout, *Cynoscion arenarius*	May	0.03	-	-	0.13	-	0.44	0.37	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Spot croaker, *Leiostomus xanthurus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	0.07	0.05	-
		July	-	-	-	-	-	-	-	-
		Aug	-	-	-	-	-	-	-	-
	Atlantic croaker, *Micropogonias undulatus*	May	-	-	-	0.65	0.16	0.29	1.34	0.50
		June	-	-	-	0.03	0.20	0.51	0.02	0.36
		July	-	-	-	0.13	0.33	0.80	0.18	0.03
		Aug	-	-	-	-	-	-	0.09	-
Clupeidae	Gulf menhaden, *Brevoortia patronus*	May	0.06	0.79	3.43	0.83	51.18	3.49	0.82	2.85
		June	-	-	4.46	-	-	0.07	-	0.05
		July	-	-	-	-	-	0.11	-	-
		Aug	-	-	-	-	-	-	0.02	-
	Gizzard shad, *Dorosoma cepedianum*	May	0.050	-	-	-	-	-	-	-
		June	0.08	0.21	-	-	-	-	-	-
		July	0.06	0.08	0.13	0.03	0.03	-	-	-
		Aug	0.03	-	-	-	-	-	-	-

	Threadfin shad, *Dorosoma petenense*	May	0.04	0.17	1.50	22.95	0.20	3.98	2.74	1.30
		June	0.05	0.83	0.03	0.13	0.06	0.44	-	0.20
		July	0.03	0.50	-	0.46	0.15	0.42	0.13	-
		Aug	0.03	-	0.07	-	-	0.03	0.04	-
Gobiidae	Darter goby, *Ctenogobius boleosoma*	May	0.01	-	-	-	-	0.02	0.09	0.10
		June	-	-	-	-	-	0.02	-	-
		July	-	-	-	-	-	0.18	0.11	-
		Aug	-	-	-	-	-	0.03	0.02	-
	Freshwater goby, *Ctenogobius shufeldti*	May	-	-	-	-	-	-	0.06	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	0.02	-	-
		Aug	-	-	-	-	-	-	-	-
	Naked goby, *Gobiosoma bosc*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	-	-	0.02	-
		Aug	-	-	-	-	-	-	-	-
Paralichthyidae	Bay whiff, *Citharichthys spilopterus*	May	-	-	0.03	0.03	-	0.02	0.40	0.70
		June	-	-	-	-	-	-	-	0.08
		July	-	-	-	-	-	0.24	0.13	0.03
		Aug	-	-	-	-	-	-	0.02	-
Achiridae	Lined sole, *Achirus lineatus*	May	-	-	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	-	-	-	-	0.03	0.02	0.09	0.10
		Aug	0.03	-	0.07	-	-	-	0.04	-
	Hogchoker, *Trinectes maculatus*	May	0.01	0.04	-	-	-	-	-	-
		June	-	-	-	-	-	-	-	-
		July	0.03	-	0.07	0.03	0.03	0.04	0.03	-
		Aug	-	-	0.04	-	-	-	0.04	-

Species Richness and Abundance

Gillnet Samples

Among all seven gillnet sampling periods, CPUE (number of fish per 10 meter of gillnet per hour of deployment) was lowest at the end of the extreme drought period in 2011 (November) and then increased nearly tenfold in December 2011. In 2012, CPUE was highest during months the barrier was closed (June and August), with CPUE in June matching CPUE estimated for December, and lowest CPUE during months the barrier was open (May and July). However, the lowest CPUE (summer 2012) was still larger than the CPUE obtained during October and November 2011 (Figure 7). Species richness (number of species per 10 m of gillnet per h of deployment) for gillnet samples was similar to patterns observed for CPUE. Richness was lowest at the end of the drought period in November 2011 and increased in December after it had rained. In 2012, species richness was highest in June (which matched richness observed during December 2011). Intermediate CPUE values were obtained during October 2011 and May, July, and August 2012 (Figure 8).

A similar pattern in species richness was observed among gillnet samples from May, July, and August 2012. Species richness increased from sites 1 to 3, was lower at sites 5 to 7, and was high at site 8. Richness was highest for all sites, except site 8, during June; species richness for site 8 was highest during August. During June, species richness was similar for sites 1 to 4 and 7 and 8; richness was lowest for site 5 (bayou sample) and highest for site 6 (Figure 9).

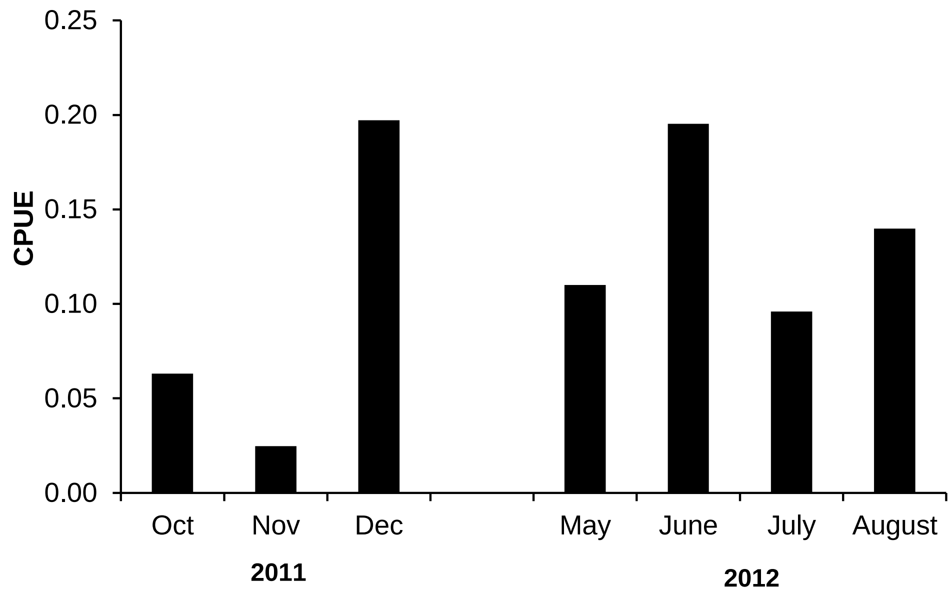

Figure 7. Average CPUE for gillnet samples (number of fish per 10 m of gillnet per h of deployment) per month during fall 2011 and summer 2012.

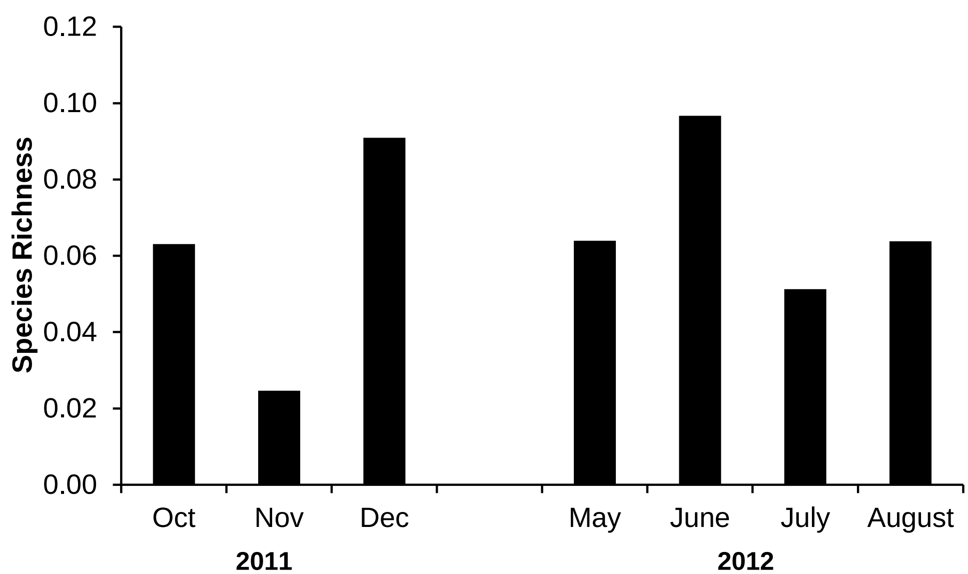

Figure 8. Average species richness for gillnet samples (number of species per 10 m of gillnet per h of deployment) per month during fall 2011 and summer 2012.

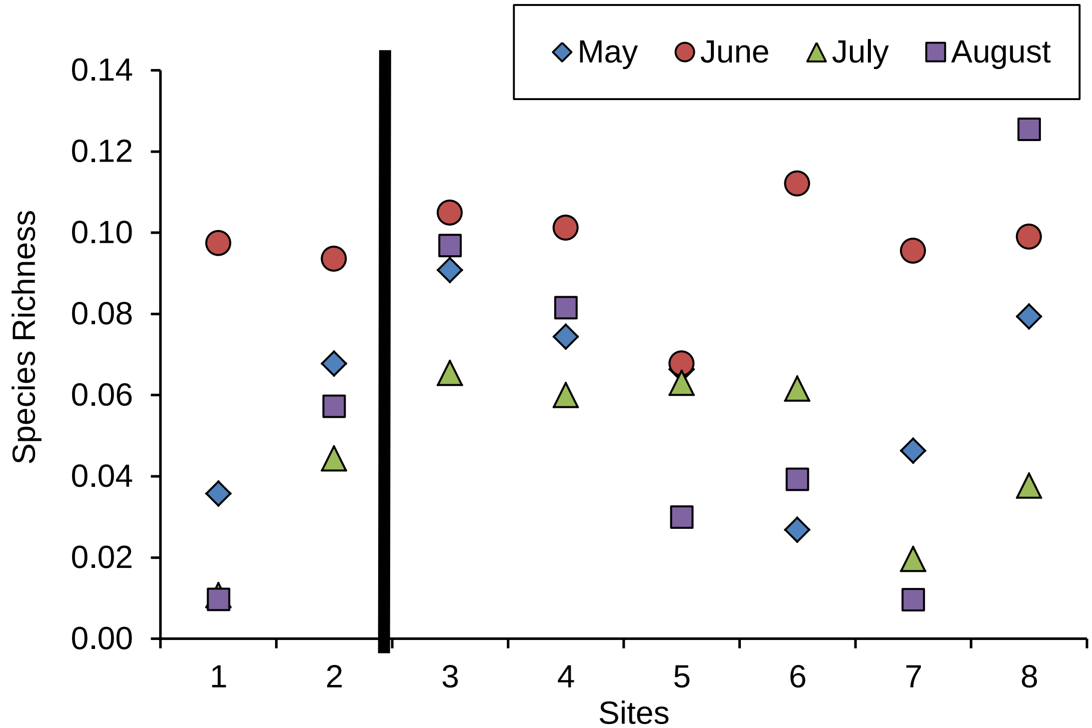

Figure 9. Species richness (number of species / 10 m of gillnet / h of net deployment) across gillnet sites per month during summer 2012. The black bar represents the location of the saltwater barrier.

Seine Samples

Analyses of seine samples from 2012 revealed that sites located above the saltwater barrier were significantly richer in species than sites located below the barrier (ANOVA; $F_{1,30} = 7.1$; $P = 0.012$), with species richness per unit effort (number of species per meter of seine haul) equal to 0.48 above the barrier and 0.30 below the barrier. Further, species richness was significantly higher in samples obtained during months the barrier was open (May and July, ANOVA; $F_{1,32} = 22.1$; $P < 0.01$). Species richness per unit effort was 0.46 while the barrier was open and 0.24 while the barrier was closed.

Species richness was lowest for sites 4 through 6 and was highest at site 2 for all months (Figure 10). Sites within close proximity to the effluent discharge pipe (sites 4, 5, and 6) had significantly lower species richness than site 2 (just above the barrier) which had the highest species richness of all sites (ANOVA; $F_{1,6} > 7.7$; $P < 0.05$); all other site values were not found to be significantly different (ANOVA; $F_{1,6} < 5.8$; $P > 0.05$). Sites 4, 5, and 6 had average species CPUE of 0.28, 0.26, and 0.24, respectively, whereas site 2 had an average species CPUE of 0.61.

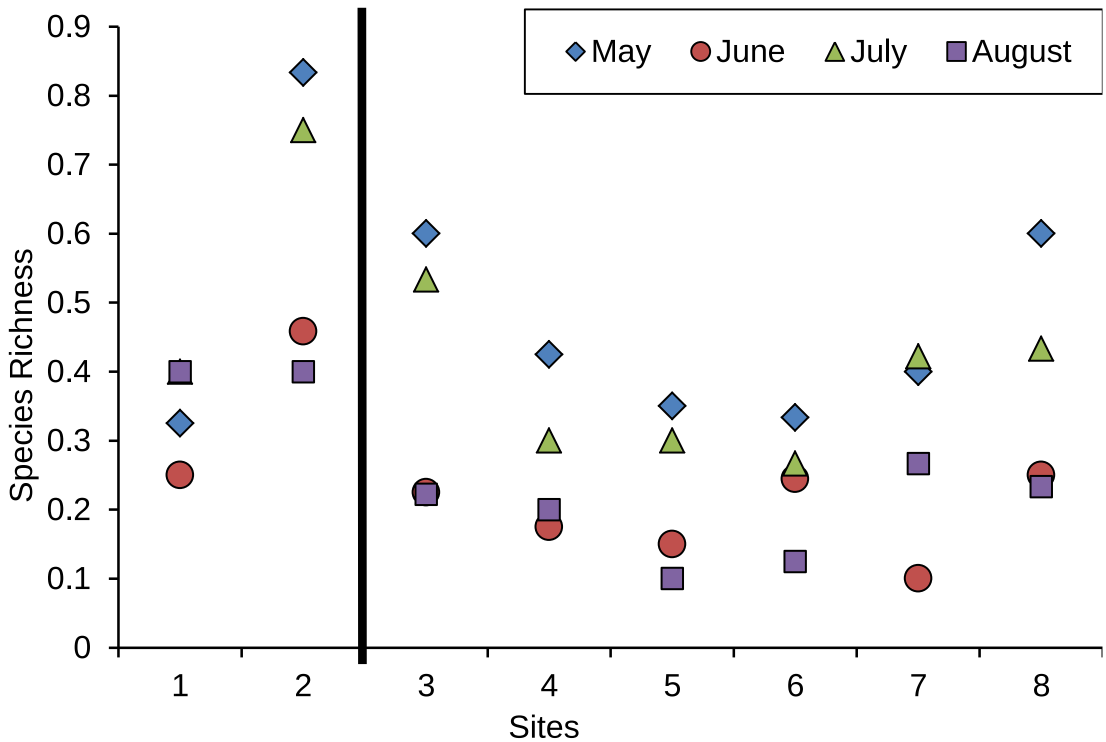

Figure 10. Species richness (number of species/m seined) across seine sites per month during summer 2012. The black bar represents the location of the saltwater barrier.

Assemblage Structure

Gillnet Samples

The nonmetric multidimensional scaling (NMDS) ordination of fish from gillnet samples showed large overlap in assemblage structure among samples regardless of survey location (above or below the barrier, Figure 11a) or period (e.g., barrier was closed vs. open, in Figure 11b). During August, sites above the barrier and sites within the bayous (indicated with “1” and “2”, respectively, Figure 11b) had assemblage structures that were divergent from all other sites. With the exception of these points, samples taken when the barrier was closed were more tightly clustered than samples taken when the barrier was open.

CPUE and relative percent abundance data reveal that only four of the thirty-eight species obtained in gillnet surveys during summer 2012 were exclusive to sites above the barrier, whereas twenty one were exclusive to sites below the barrier; all other species showed no clear distribution patterns based on sampling location. Certain species, such as *Aphredoderus sayanus*, *Cyprinella venusta, Cyprinus carpio,* and *Pylodictis olivaris,* were only captured at sites above the barrier, whereas others, including *Archosargus probatocephalus, Atractosteus spatula, Sciaenops ocellatus, Ictalurus punctatus,* and *Morone* spp., were only captured below the barrier. Eight species were exclusive to samples taken when the barrier was open (obtained during May or July), and six species were exclusive to samples taken when the barrier was closed (obtained during June or August); all other species showed no clear pattern based on sample location or time period. *Brevoortia patronus* had highest relative abundance during May and August (23% and 31% of total individuals were caught during those two months, respectively). *Brevoortia patronus* was unevenly distributed among sites; this species was abundant at site 8 during May and distributed throughout sites 2-8 during August. Collectively, *Lepisosteus osseus* and *Lepisosteus oculatus* had highest relative abundances in June and July (32% and 35%, respectively), the second highest relative abundance in May (13%), and were distributed throughout most sites (*L. osseus* was not found at site 5 during summer 2012). The two outlier samples in the far left of the NMDS ordination (‘1’ and ‘2’ in Figure 11b) had only 1 species each. *Aplodinotus grunniens* was the only species obtained at site 1, and *Lepomis macrochirus* was the only species obtained from site 7; each of these species were only obtained from one other site within the periods when they were recorded.

Seine Samples

The NMDS ordination of seine data revealed overlap in assemblage structure of samples taken above and below the barrier, however the degree of overlap depended

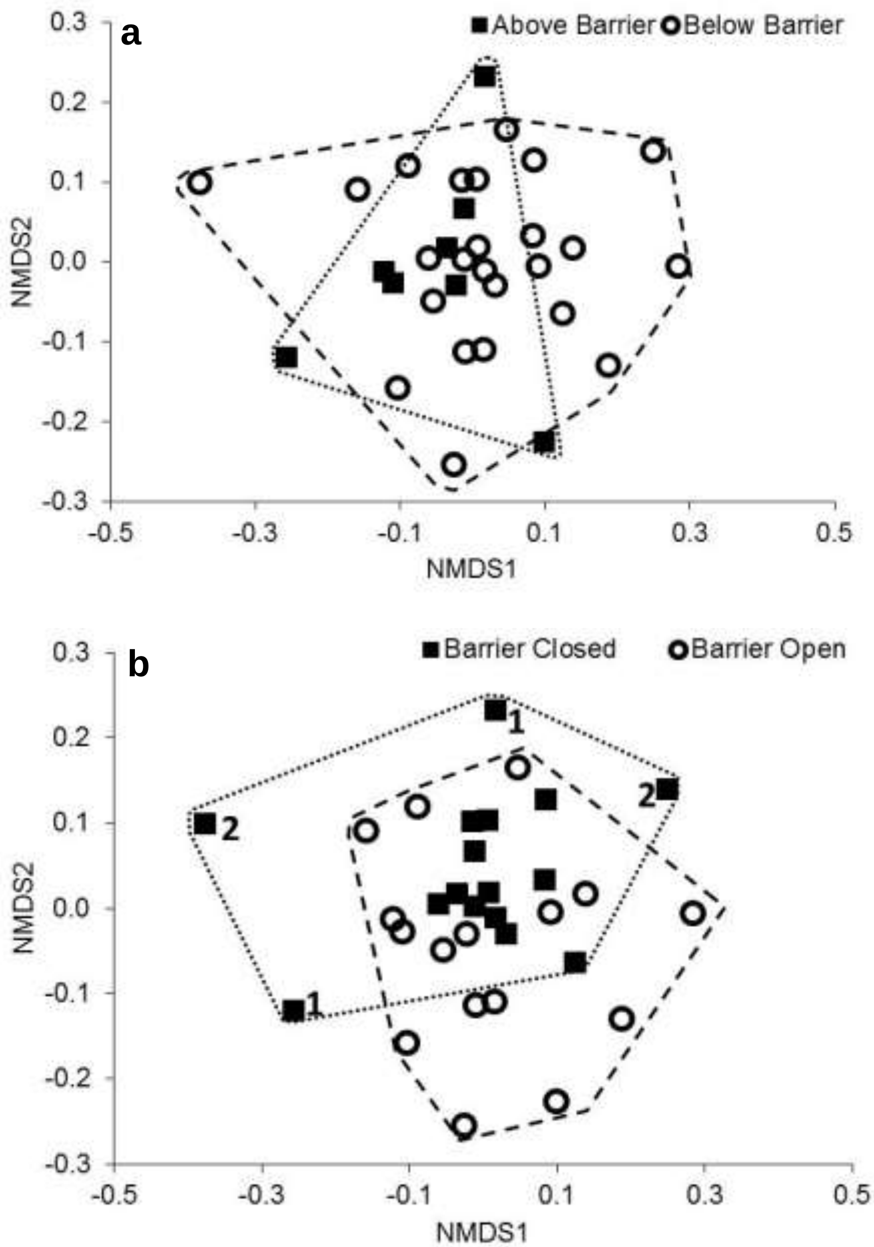

Figure 11. NMDS ordination plots of gillnet samples classified by **a**) the sampling location relative to the saltwater barrier (dotted line surrounds samples above the barrier; dashed line surrounds samples below the barrier) and **b**) when the barrier was closed (dotted line) or open (dashed line) during the survey (the two outliers are 1 = August 2012 sample taken above the barrier; 2 = August 2012 sample taken within the bayous).

on whether the barrier was open or closed. Assemblage structure of samples taken during May (enclosed by the dashed line in Figure 12) was distinct from other samples; May samples taken below the barrier were more similar to each other than May samples from above the barrier. Samples taken when the barrier was closed (enclosed by the solid line in Figure 12) had different assemblage structures than samples taken when the barrier was open. When the barrier was closed, samples taken below the barrier were more similar to each other than to samples taken above the barrier.

CPUE and relative abundance data reveal that ten species were exclusive to seine sites above the barrier, whereas fourteen species were exclusive to sites below the barrier, regardless of whether the barrier was open or closed. Nine species were exclusive to May, seven species were exclusive to samples obtained while the barrier was open, and no species were exclusive to samples obtained while the barrier was open (two species exclusive to June consisted of less than 0.1% relative abundance). Six species, including *B. patronus, Ctenogobius boleosoma, I. punctatus,* and *Lepomis microlophus*, were only found above the barrier during May (these species were found at sites below the barrier during other months). Several species, including *Cynoscion arenarius, Cyprinella lutrensis, Macrhybopsis hyostoma,* and *Notropis sabinae,* were only captured during May. *Dorosoma cepedianum* and *Pimephales vigilax* were only found at sites below the barrier during periods when the barrier was open. Marine and brackish species, such as *Micropogonias undulatus* and *Syngnathus scovelli,* were abundant at sites below the barrier. *Trinectes maculatus* also was most common below the barrier, however, it was found above the barrier during months the barrier was open. Samples from site 3 (outlier in the lower central area of the NMDS ordination, Figure 12) contained species that tended to have greater abundance upstream of the barrier (e.g., *Labidesthes sicculus* and *Notropis texanus*) as well as species more common below the barrier (e.g., *B. patronus* and *Citharichthys spilopterus)*. Site 3 also lacked several species common upstream of the barrier (e.g., *D. cepedianum* and *Lythrurus fumeus*) and downstream of the barrier (e.g., *M. undulatus* and *Mugil cephalus*).

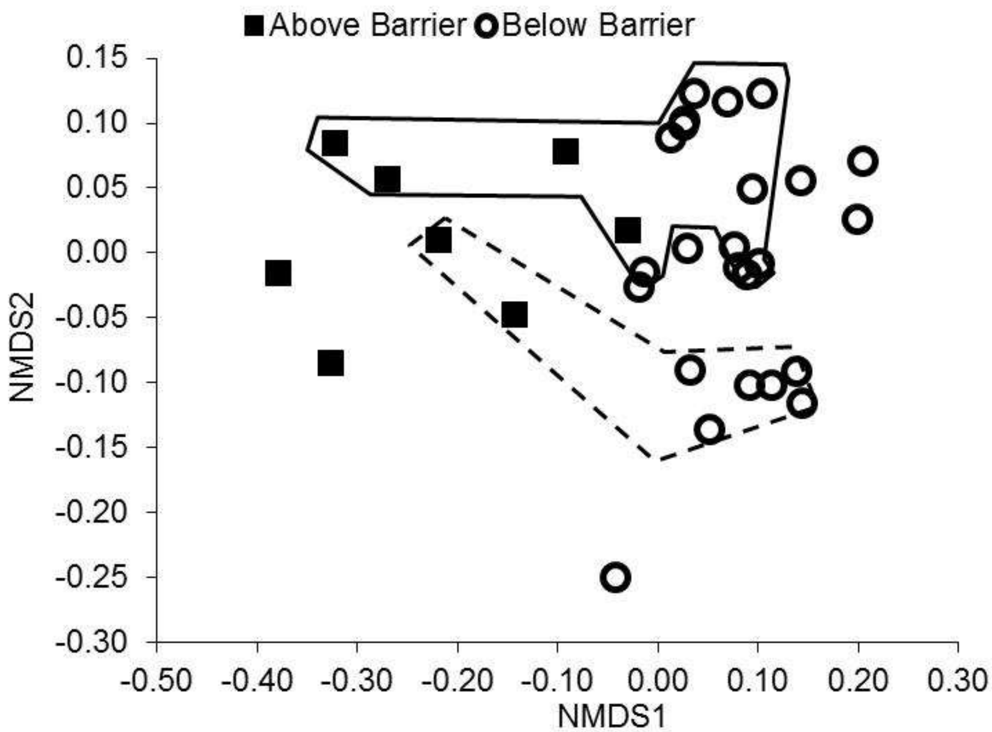

Figure 12. NMDS ordination plot of seine samples classified by location relative to the saltwater barrier (above or below). The solid line encloses samples taken during months when the barrier was closed, dashed line encloses samples taken during May 2012, and unenclosed samples were taken during July 2012.

Water Quality

Water temperatures varied among seasons. In 2011, temperature ranged from 19.6–22.0ºC during November, and from 13.2–14.7ºC during December. During the summer 2012 temperature the lowest temperature recorded during May at 24.6ºC (site 1) and warmest during August at 30.6ºC (site 5).

Salinity levels above the barrier were 0.08 and 0.1 ppt in November 2011 and December 2011, respectively. Below the barrier, salinity levels ranged from 13.3–15.8 ppt in November 2011, and dropped to 6.1–8.0 ppt in December 2011 (Figure 13a). Salinity ranged from 0.0–0.1 ppt above the barrier, and from 0.0–1.3 ppt below the barrier throughout summer 2012 (Figure 13b). Salinity below the barrier was significantly higher during the months the barrier was closed than months the barrier was open (ANOVA; $F_{1,22} = 20.7$; $P < 0.0001$). Salinity levels above the barrier remained relatively constant throughout the summer of 2012.

Dissolved oxygen (DO) above the barrier was 7.8 and 8.4 mg/L during November and December, 2011, respectively. Below the barrier DO averaged 5.3 mg/L in November and increased significantly in December to an average of 6.9 (ANOVA; $F_{1,8} = 80.1$; $P < 0.0001$) (Figure 14a). DO levels during May 2012 were similar to levels measured during December 2012, but were significantly higher than levels measured during all other summer months in 2012 and November 2011 (ANOVA; $F_{1,14} > 15.3$; $P < 0.01$). DO levels measured during June and August were similar, whereas levels measured during July were significantly lower than all months during both fall 2011 and summer 2012 (ANOVA; $F_{1,14} > 41.9$; $P < 0.0001$) (Figure 14b).

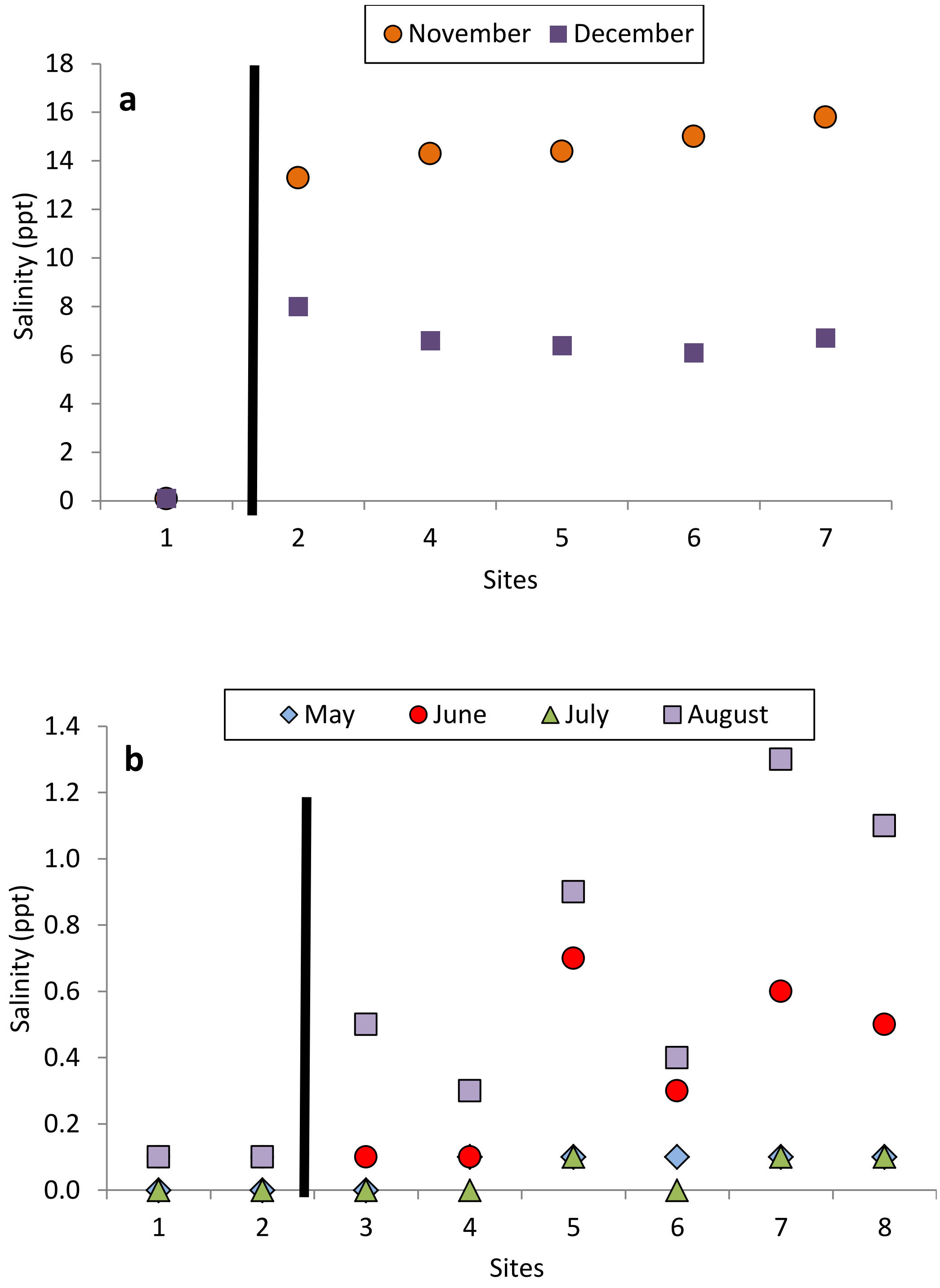

Figure 13. Salinity measurements (3 meters below the surface) along the Neches River during **a**) fall 2011 and **b**) summer 2012. The vertical bar represents the location of the saltwater barrier.

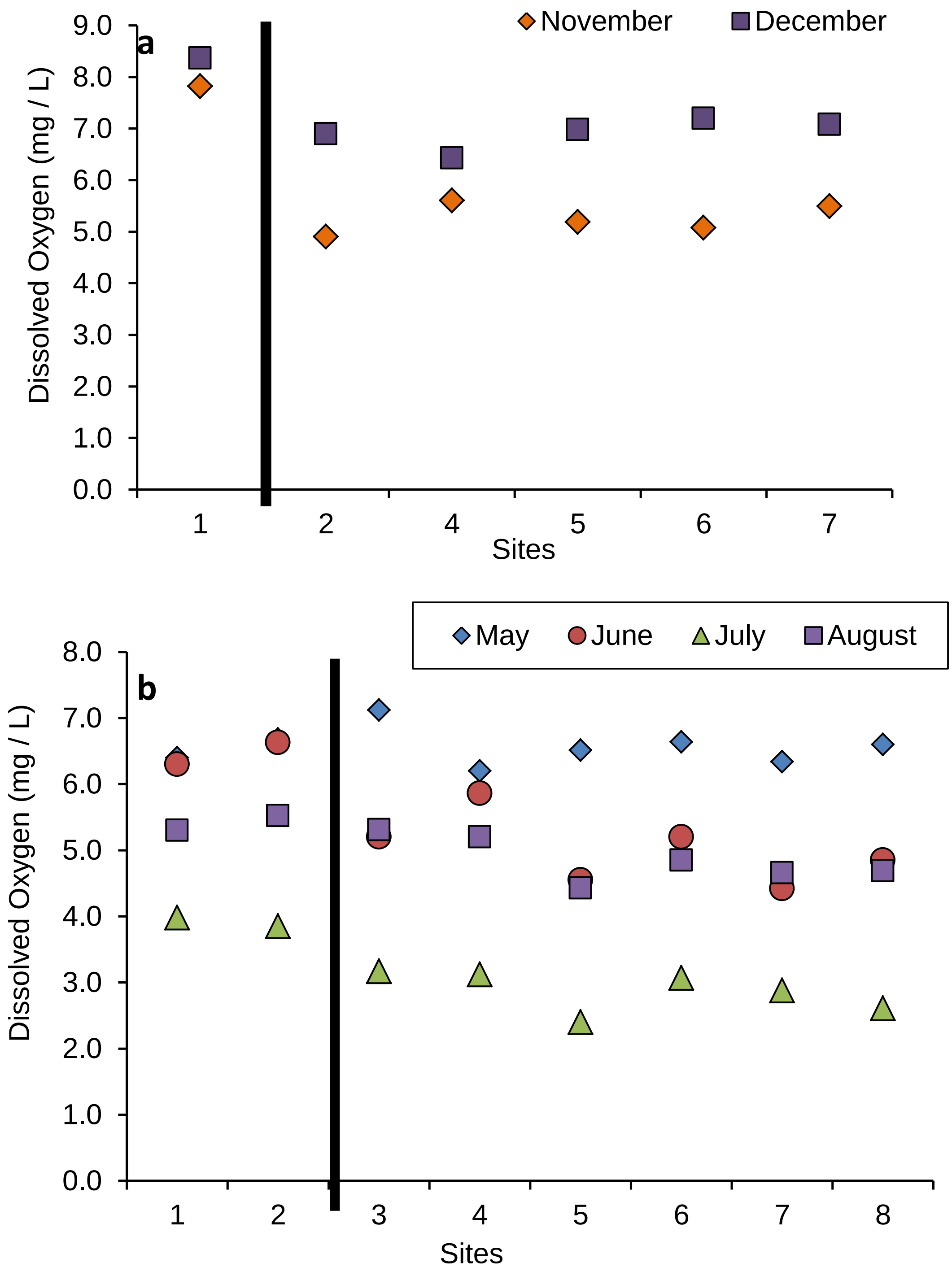

Figure 14. Dissolved oxygen measurements along the Neches River during **a**) fall 2011 and **b**) summer 2012. The vertical bar represents the location of the saltwater barrier.

Environment – Fish Assemblage Relationships

Canonical correspondence analysis (CCA) performed with species CPUE data and seven environmental variables yielded stronger ordinations for seine samples than gillnet samples (Tables 8 and 9). For May 2012 gillnet samples, axis 1 contrasted sites based on salinity, conductivity, and temperature; sites 5 and 8 had strong associations with these variables and were dominated by *B. patronus*, *M. cephalus,* and *Sciaenops ocellatus*. The second axis contrasted sites based on DO levels; sites with high negative scores on axis 2 were dominated by *Pomoxis annularis* and *Lepisosteus occulatus*.

The first axis of the CCA for June 2012 was strongly correlated with salinity and conductivity; sites 5 and 8 were strongly associated with these environmental variables and were dominated by *Leiostomus xanthurus, B. patronus,* and *S. ocellatus*. The second axis was strongly correlated with DO; sites with higher DO were most associated with the species *Alosa chrysochloris, Dorosoma petenense,* and *L. osseus*.

Axis 1 for July 2012 samples most strongly contrasted sites based on salinity and temperature; sites associated with low salinities (all sites except 5 and 8) were dominated by *L. ossesus, L. oculatus,* and *I. bubalus*. Conductivity and pH were correlated with the second axis. Site 5 had a relatively high conductivity level and low pH, and was dominated by *Lepomis megalotis* and *Lepomis microlophus*.

None of the water quality parameters scored highly on the first axis for August 2012 samples; site 1 and *Aplodinotus grunniens* were positively correlated with axis 1. Axis 2 contrasted sites with higher DO, temperature, and depth with sites having higher pH, salinity, and conductivity. Sites with higher pH, salinity, and conductivity were dominated by *A. grunniens* and *M. cephalus,* whereas sites with greater DO, temperature, and depth were dominated by *B. patronus* and *Ictalurus furcatus* (Figure 15, Appendices 2-5).

Table 8. Axis summary statistics for the first two axes from CCA analysis performed on fish gillnet data.

		Eigenvalue	Percent Variance Explained	Pearson Correlation Species-Environment
May	Axis 1	0.78	28.4%	1.0
	Axis 2	0.53	19.1%	1.0
June	Axis 1	0.48	34.6%	1.0
	Axis 2	0.30	21.8%	1.0
July	Axis 1	0.76	27.0%	1.0
	Axis 2	0.70	24.9%	1.0
August	Axis 1	0.75	25.1%	1.0
	Axis 2	0.70	23.2%	1.0

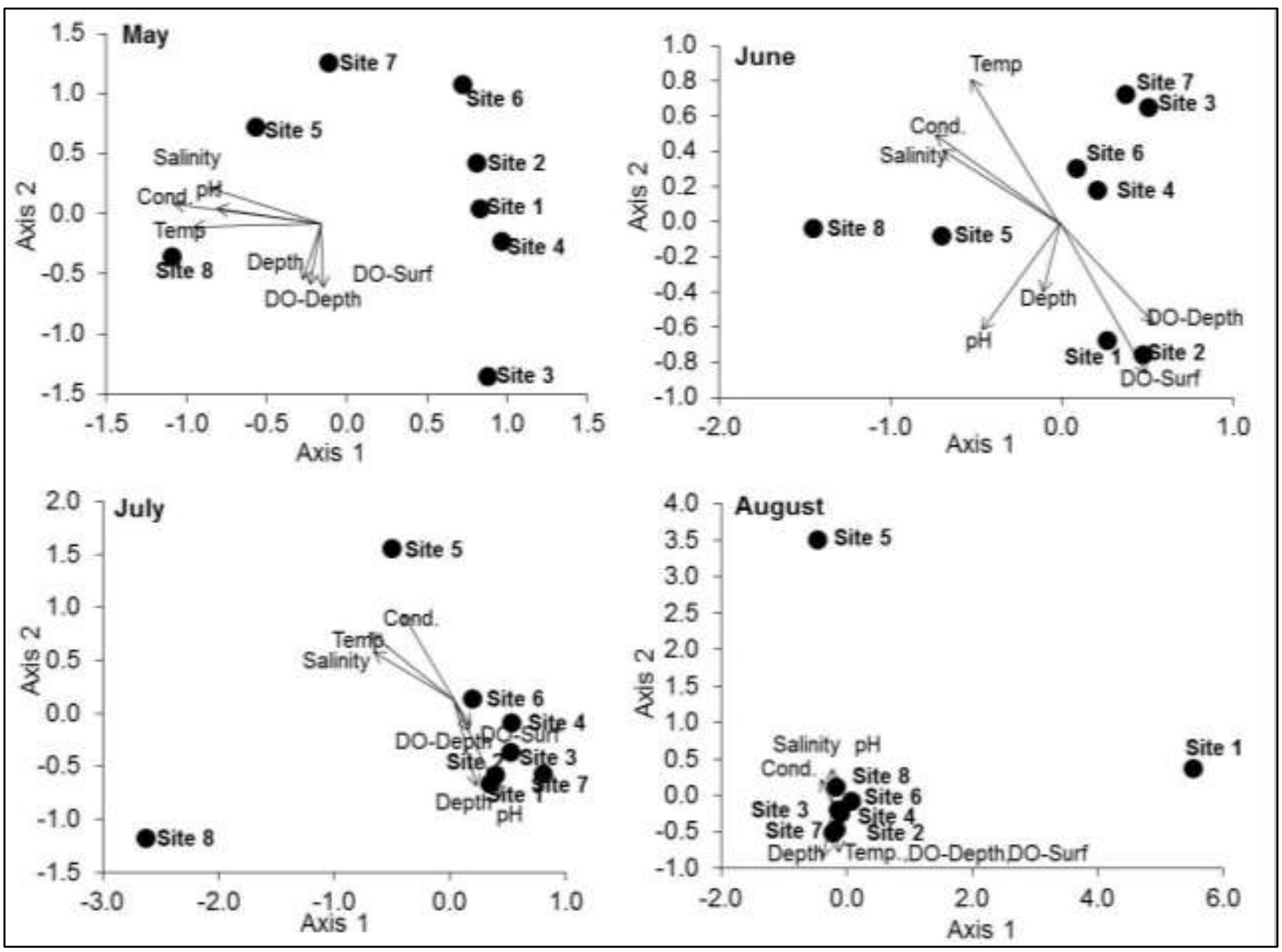

Figure 15. Canonical Correspondence Analysis (CCA) of fish CPUE from gillnet surveys and 7 physiochemical variables measured at 8 sites each month during summer 2012. Dissolved oxygen at a depth of 10 feet = DO-Depth, dissolved oxygen measured just below the surface = DO-Surf, Temperature = Temp, and Conductivity = Cond.

For May seine samples, the first axis contrasted sites based on salinity and temperature; sites associated with larger values for these variables were dominated by *A. mitchilli, M. beryllina,* and *D. petenense*. CCA axis 2 contrasted sites with higher DO from sites having higher pH and conductivity. *Brevoortia patronus* dominated sites with higher DO*; C. arenarius, M. undulatus,* and *C. spilopterus* were more common at sites with higher pH and conductivity.

During June, pH most strongly differentiated sites, and those with lowest pH (high scores on CCA 1) were dominated by *B. patronus*. CCA axis 2 contrasted sites with higher DO from those having higher salinity, conductivity, and temperature. Sites with higher DO tended to have more *P. vigilax, C. venusta,* and *O. emiliae,* whereas sites associated with higher temperature, salinity, and conductivity were dominated by *A. mitchilli, M. beryllina,* and *M. undulatus.*

During July, CCA axis 1 was correlated with DO; sites 1 and 2 had higher DO levels and had many *P. vigilax, Notropis volucellus,* and *Fundulus notatus*. Axis 2 was most strongly correlated with salinity; higher salinities were associated with *M. beryllina, M. undulatus,* and *C. spilopterus*.

Both CCA axes in August contrasted sites with higher salinity and conductivity with sites having higher DO. Sites with higher DO were dominated by *C. venusta, Notropis texanus,* and *P. vigilax*, whereas sites with higher salinity levels were associated with *A. mitchilli* and *M. beryllina* (Figure 16, Appendices 6-9).

Table 9. Summary statistics for the first two axes from CCA performed on fish gillnet data.

		Eigenvalue	**Percent Variance Explained**	**Pearson Correlation Species-Environment**
May	Axis 1	0.78	28.4%	1.0
	Axis 2	0.53	19.1%	1.0
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	Axis 2	0.30	21.8%	1.0
July	Axis 1	0.76	27.0%	1.0
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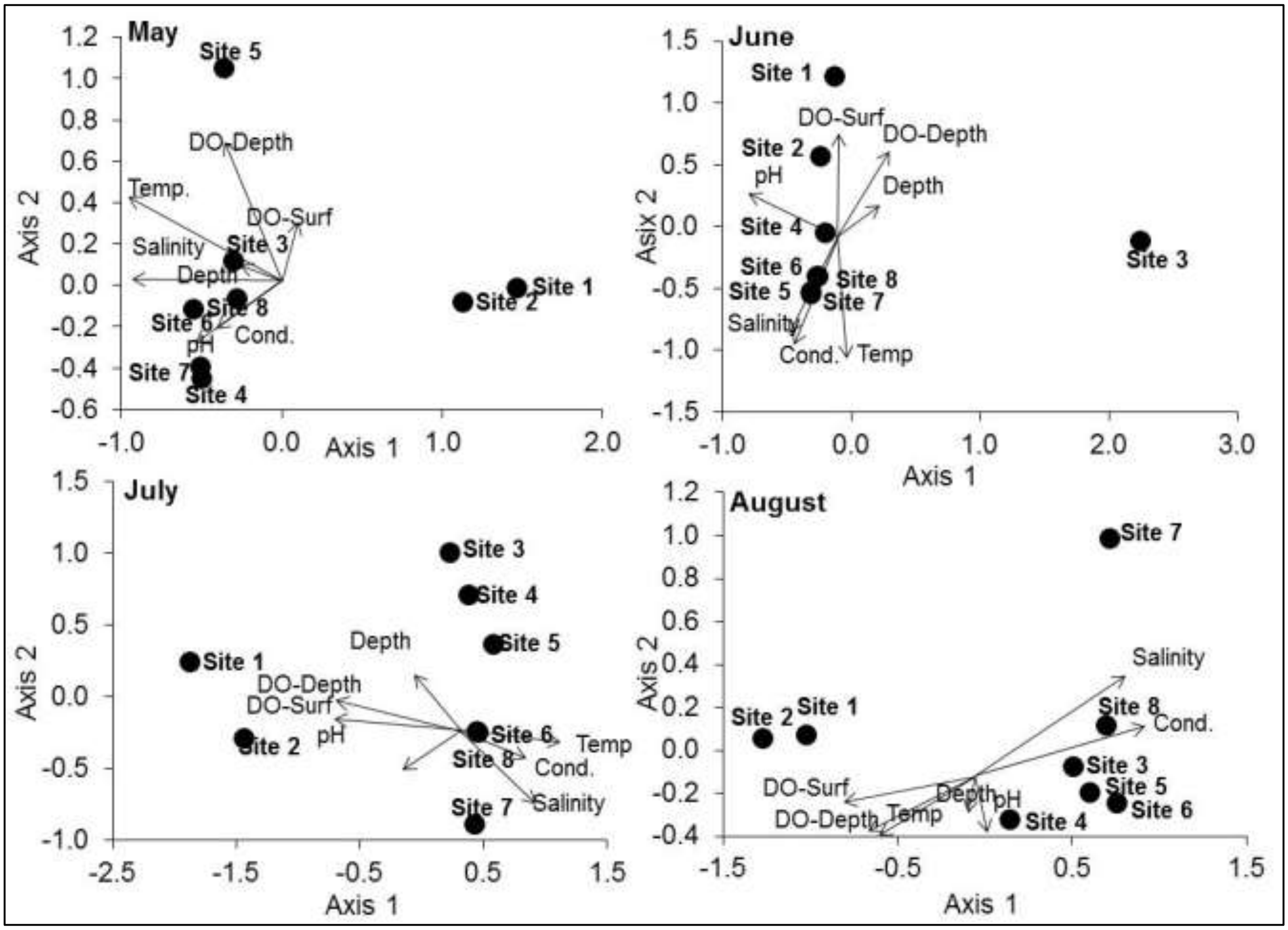

Figure 16. Canonical correspondence analysis (CCA) of fish CPUE from seine surveys and seven physiochemical variables measured at eight sites each month during summer 2012. Dissolved oxygen at a depth of 10 feet = DO-Depth, dissolved oxygen measured just below the surface = DO-Surf, Temperature = Temp, and Conductivity = Cond.

Indicator Fish Species

Among the 63 fish species captured during the field surveys, 17 were deemed suitable indicators given their intolerance of salinity and/or low dissolved oxygen. Some species, such as white bass (spawning migrations enhanced by high flow pulses during early spring, alligator gar also were listed by Bio-West (2009) as species with life history attributes that can be used as indicators for various aspects of a flow regime that would maintain the historic aquatic communities of the study area. Among fishes native to this area, the mimic shiner (*Notropis volucellus*), brook silverside (*Labidesthes sicculus*), and dusky darter (*Percina sciera*) may be particularly sensitive indicators of suitable water quality, in terms of insensitivity to both salinity and low dissolved oxygen (Linam and Kleinsasser 1998).

Table 10. List of fish species captured from the study reach during the 2011-2012 field surveys. Checkmarks indicate those species determined to be intolerant to salinity or aquatic hypoxia or have life history attributes sensitive to flow variation according to the literature sources reviewed. Species in boldface type are intolerant of high salinity; species underlined are species that also are sensitive to reductions in dissolved oxygen. These species may be candidates for monitoring studies designed to evaluate subsistence flow requirements in the study area.

		Intolerance to		Sensitive to Flow
Family	Species	Salinity	Hypoxia	Variation
Lepisosteidae	Alligator gar, *Atractosteus spatula*			√
	Spotted gar, *Lepisosteus oculatus*			
	Longnose gar, *Lepisosteus osseus*			
Elopidae	Ladyfish, *Elops saurus*			
Clupeidae	Skipjack shad, *Alosa chrysochloris*			
	Gulf menhaden, *Brevoortia patronus*			
	Gizzard shad, *Dorosoma cepedianum*			
	Threadfin shad, *Dorosoma petenense*			
Engraulidae	Bay anchovy, *Anchoa mitchilli*			
Cyprinidae	Red shiner, *Cyprinella lutrensis*			
	Blacktail shiner, *Cyprinella venusta*	√		
	Ribbon shiner, *Lythrurus fumeus*	√		
	Shoal chub, *Macrhybopsis hyostoma*	√		√
	Golden shiner, *Notemigonus crysoleucas*			
	Sabine shiner, *Notropis sabinae*	√		√
	Weed shiner, *Notropis texanus*	√		
	<u>**Mimic shiner, *Notropis volucellus***</u>	√	√	
	Pugnose minnow, *Opsopoeodus emiliae*	√		
	Bullhead minnow, *Pimephales vigilax*	√		
Catostomidae	**Smallmouth buffalo, *Ictiobus bubalus***	√		
Ictaluridae	Blue catfish, *Ictalurus furcatus*			
	Channel catfish, *Ictalurus punctatus*			
Mugilidae	Striped mullet, *Mugil cephalus*			
Atherinopsidae	<u>**Brook silverside, Labidesthes sicculus**</u>	√	√	

	Inland silverside, *Menidia beryllina*			
Belonidae	Atlantic needlefish, *Strongylura marina*			
Fundulidae	Gulf killifish, *Fundulus grandis*			
	Blackstripe topminnow, *Fundulus notatus*	√		
	Rainwater killifish, *Lucania parva*			
Cyprinodontidae	Sheepshead minnow, *Cyprinodon variegatus*			
Poeciliidae	Western Mosquitofish, *Gambusia affinis*			
	Least killifish, *Heterandria formosa*			
	Sailfin molly, *Poecilia latipinna*			
Moronidae	White bass, *Morone chrysops*			√
	Yellow bass, *Morone missisippiensis*			
Centrarchidae	**Flier, *Centrarchus macropterus***	√		
	Green sunfish, *Lepomis cyanellus*	√		
	Warmouth, *Lepomis gulosus*			
	Bluegill, *Lepomis macrochirus*	√		
	Longear sunfish, *Lepomis megalotis*	√		
	Redear sunfish, *Lepomis microlophus*			
	Redspotted sunfish, *Lepomis miniatus*	√		
	Spotted bass, *Micropterus punctulatus*	√		√
	Largemouth bass, *Micropterus salmoides*			
	White crappie, *Pomoxis annularis*	√		√
Percidae	**Bluntnose darter, *Etheostoma chlorosomum***	√		
	<u>**Dusky darter, *Percina sciera***</u>	√	√	√
Sparidae	Sheepshead, *Archosargus probatocephalus*			
Sciaenidae	Freshwater drum, *Aplodinotus grunniens*			
	Sand seatrout, *Cynoscion arenarius*			
	Spot croaker, *Leiostomus xanthurus*			
	Atlantic croaker, *Micropogonias undulatus*			
	Red drum, *Sciaenops ocellatus*			
Eleotridae	Fat sleeper, *Dormitator maculatus*			
Gobiidae	Darter goby, *Ctenogobius boleosoma*			
	Freshwater goby, *Ctenogobius shufeldti*			
	Naked goby, *Gobiosoma bosc*			
Paralichthyidae	Bay whiff, *Citharichthys spilopterus*			
	Southern flounder, *Paralichthys lethostigma*			
Achiridae	Lined sole, *Achirus lineatus*			
	Hogchoker, *Trinectes maculatus*			
Syngnathidae	Opossum pipefish, *Microphis brachyurus*			
	Gulf pipefish, *Syngnathus scovelli*			

Estimated Flow Deficits Saltwater Barrier Gage

Only nine years of historical flow data (January 2004 to December 2012) from the gage at the Saltwater Rarrier were available to examine flow fluctuations and potential water deficit in the lower Neches below the saltwater barrier. To estimate of the amount of water flowing to the location of the Saltwater Barrier on the lower Neches River, mean daily discharges were obtained from stream gates at Evadale, Village Creek, and Pine Island Bayou (Figure 17). The cumulative flow from these three gages was used to identify periods of water deficit below the saltwater barrier over the past 9 years and to estimate the magnitudes of daily deficits. This calculation consisted of flows at the saltwater barrier gage minus the sum of flows at the Evadale + Village Creek + Pine Island Bayou gages (Figure 18). These estimates do not account for water flowing into local bayous or the discharge from the Meade Westvaco pulp and paper mill. These estimates also do not account for water diversions above the Saltwater Barrier, including water extracted for municipal water supplies.

Lower Neches River flows appear to be highly dependent on main-channel contributions flowing downstream from Evadale (average 4240 cfs). Inter-annual mean discharge did not change much between years 2004–2005 (Figure 16), but large flow fluctuations were observed between January 2006 and January 2008, with a recovery between April 2008 and October 2010. In 2011, flows were extremely low due to the drought. This analysis reveals net water deficit below the saltwater barrier during periods of drought (Figure 18).

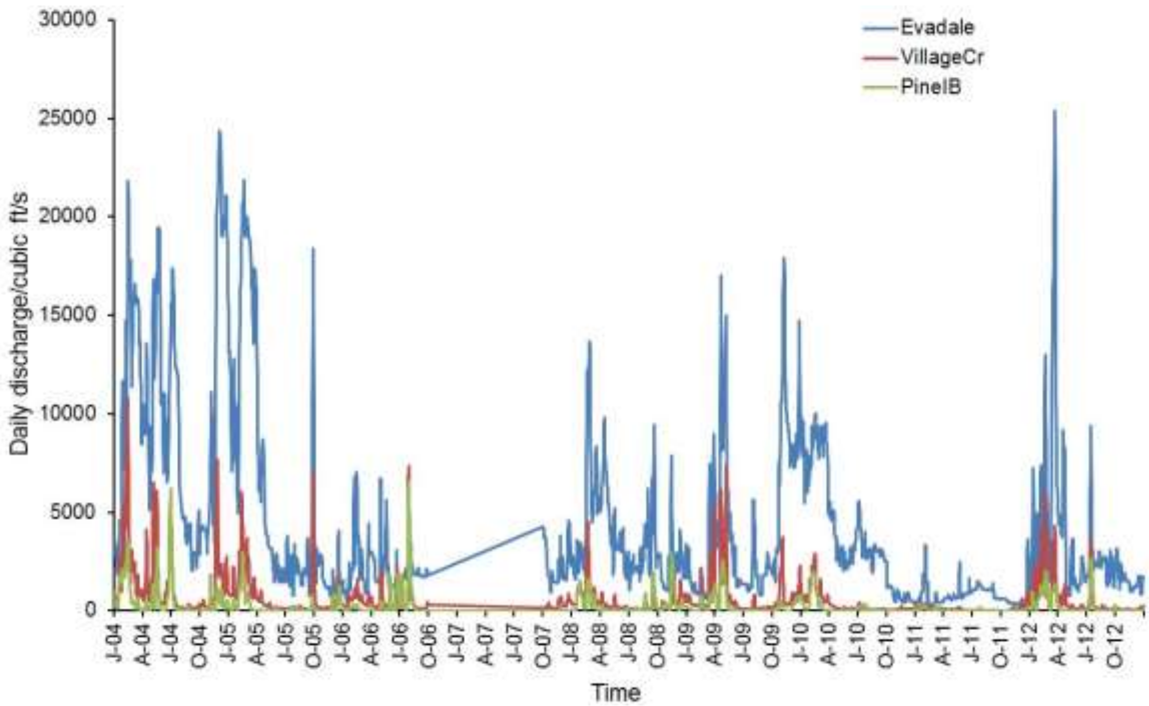

Figure 17. Daily mean discharge rates (cfs) from January 1, 2004 to December 31, 2012, for three USGS gages with flows that contribute to the lower Neches River.

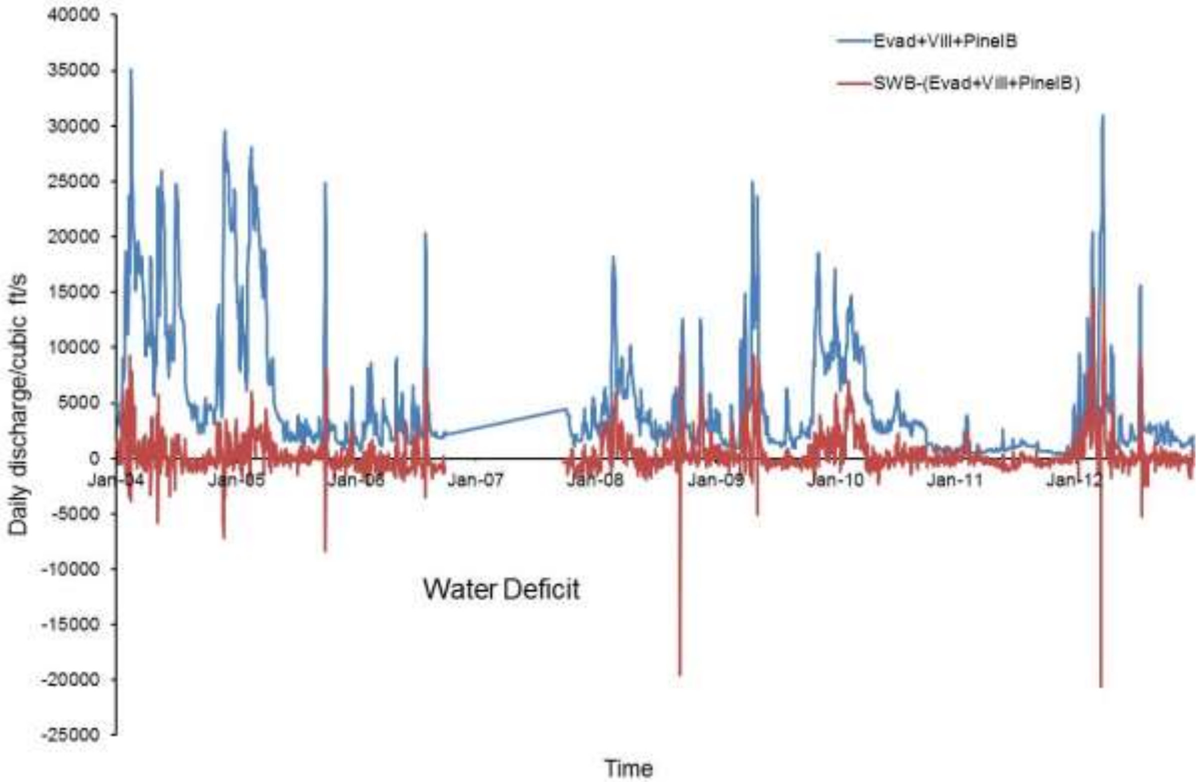

Figure 18. Cumulative daily mean discharge rates (cubic feet per second) for the Neches River above the Salt Water Barrier (SWB) and the flow received at the SWB, which is the difference between the discharge at the SWB minus flows about the flows originated above the barrier (Evadale+ Village Cr + Pine Isl Bayou). Data from January 1, 2004 to December 31, 2012.

Environmental Flow Regime for the Lower Neches River

The estimated flow regime for the Saltwater Barrier gage from 1968 to 2011 appears in Figure 19, and data and calculations are provided in Appendix 9.

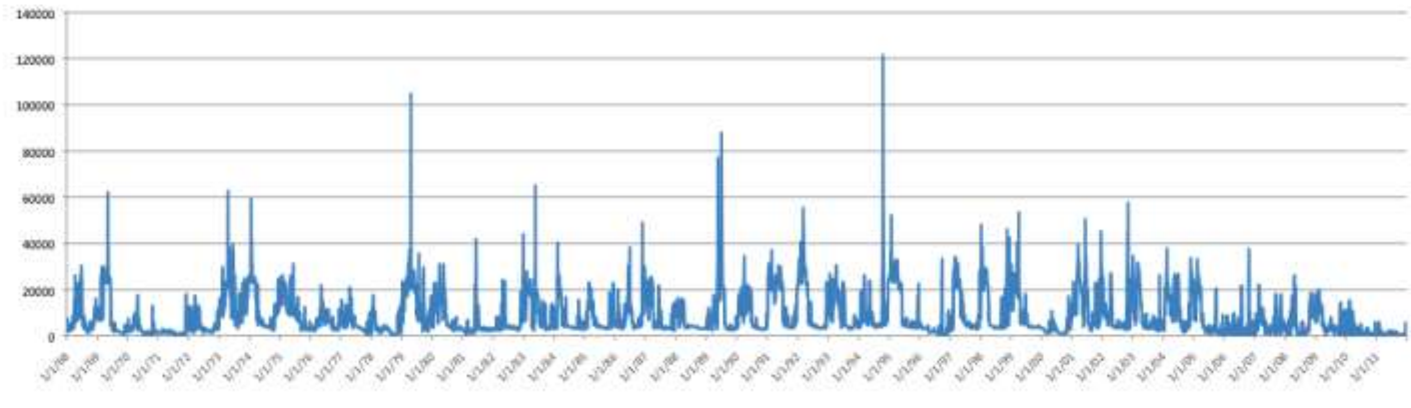

Figure 19. Estimated flows (cfs) at the Saltwater Barrier from 1968-2011.

Table 11. Environmental flow regime for the lower Neches River at the Saltwater Barrier gage derived from HEFR analysis.

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Events	Qp: 39,598 cfs with Average Frequency 1 per 2 years Regressed Volume is 869,078 to 4,607,551 (2,001,079) Regressed Duration is 21 to 124 (51)			
	Qp: 28,685 cfs with Average Frequency 1 per year Regressed Volume is 473,089 to 2,502,570 (1,088,089) Regressed Duration is 14 to 85 (35)			
High Flow Pulses	Qp: 13,609 cfs with Average Frequency 1 per season Regressed Volume is 116,580 to 746,515 (295,007) Regressed Duration is 6 to 44 (16)	Qp: 10,815 cfs with Average Frequency 1 per season Regressed Volume is 77,494 to 348,727 (164,391) Regressed Duration is 5 to 24 (11)	Qp: 5,610 cfs with Average Frequency 1 per season Regressed Volume is 28,291 to 132,230 (61,164) Regressed Duration is 3 to 14 (7)	Qp: 11,292 cfs with Average Frequency 1 per season Regressed Volume is 66,432 to 348,023 (152,052) Regressed Duration is 4 to 24 (10)
	Qp: 5,378 cfs with Average Frequency 2 per season Regressed Volume is 16,273 to 104,541 (41,245) Regressed Duration is 2 to 13 (4)	Qp: 4,740 cfs with Average Frequency 2 per season Regressed Volume is 14,944 to 67,367 (31,729) Regressed Duration is 2 to 8 (4)	Qp: 4,158 cfs with Average Frequency 2 per season Regressed Volume is 16,532 to 77,413 (35,774) Regressed Duration is 2 to 10 (5)	Qp: 5,120 cfs with Average Frequency 2 per season Regressed Volume is 17,332 to 90,767 (39,663) Regressed Duration is 2 to 11 (4)
Base Flows (cfs)	3526 (74.8%)	4223 (67.6%)	3813 (45.7%)	3401 (52.0%)
	2583 (84.7%)	2870 (82.2%)	3207 (65.6%)	2841 (68.7%)
	1641 (91.0%)	1900 (89.7%)	1919 (81.8%)	2020 (80.4%)
Subsistence Flows (cfs)	1166 (95.0%)	1265 (95.0%)	912 (95.0%)	617 (95.0%)

Base Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)

Pulse volumes are in units of acre-feet and durations are in days.
Period of record used : 1/1/1968 to 12/31/2011.
Q95 calculation used for subsistence flows. Annual Q95 value is 890.686956521739 cfs.

The biological evaluation of the environmental flow regime derived from the HEFR analysis did not identify any flow components that were redundant for maintenance of a sound ecological environment in the lower Neches and associated aquatic and wetland habitats in its riparian zone within the study area. Based on the concept of the natural flow regime (Poff et al. 1997), the magnitudes and frequencies of each flow component is required during the four seasons in order to maintain the full complement of native species in this ecosystem. Given the flow regime implementation rules that have been adopted by the TCEQ for environmental flow standards, the average frequencies of these flow components will decline when water is permitted for human uses. For example, if water can be diverted down to the subsistence value during a dry period, after which no further diversions are allowed, flows are likely to decline subsequent to the cessation of diversion. This implementation policy will result in long-term averages for low flows that are lower than the averages from the current historical record. Similarly, a certain number of high flow pulses are protected based on average frequencies of occurrence based on the current historical flow record, and diversions of any additional high flow pulses are permitted whenever they occur. This implementation rule will result in future reductions of the average frequencies of occurrence for a given tier of high flow pulse (i.e., the running average would trend downward as frequencies less than the mean frequency are protected, but frequencies above the mean are reduced due to diversion or storage for diversion).

Subsistence Flows

Recommended subsistence flows for the lower Neches River are 1,166 cfs (winter), 1,265 cfs (spring), 912 cfs (summer), and 617 cfs (fall). Based on the instream flow incremental methodology and physical habitat simulation modeling for a reach of the Neches River below the mouth of Village Creek, Werner (1982) estimated monthly environmental flows under drought conditions that ranged from 200 cfs (August) to 1,500 cfs (April). However, his location was located upstream from the study area, and did not include inflows from points downstream from Village Creek, including discharge from Pine Island Bayou.

The lack of flows in the lower Neches during the severe drought of 2011 were associated with a large increases in salinity and reductions in dissolved oxygen at most of the survey sites below the Saltwater Barrier. During summer 2012 when there were flow flows but also some periods with moderate high flow pulses, salinities at survey sites below the barrier never exceeded 2 ppt, but dissolved oxygen was very low at most sites below the barrier during July (~ 3 mg/L) and August (~ 5 mg/L). Even the survey site above the barrier had reduced dissolved oxygen during July–August 2012, and this may have been driven by microbial respiration from organic matter washed into the river during rainfall events that followed periods without rainfall. In any case, it appears that current flows during periods of low rainfall with long intervals between runoff events and flow pulses is associated with significant increases in salinity and reductions water quality in aquatic habitats below the Saltwater Barrier. The seasonal subsistence flow recommendations based on the 5th percentile of historic low flows (Q95) should be considered the minimum estimate, and given the current situation with dissolved organic matter discharged from the MeadeWestvaco pulp and paper mill and the future situation with the deepening of the ship channel, subsistence flows may need to be increased to protect the ecosystem. Currently, the flow is essentially 0 cfs during extended periods of low flow, such as the major drought of 2011.

The riparian forest of the study area is dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatic*), trees that are flood tolerant yet salt sensitive (Pezeshki 1990, GC-CESU 2011). Previous studies have documented detrimental effects of salinities as low as 1.3 ppt on these trees and their seedlings, and prolonged exposure to salinities as low as 6 ppt causes mortality (Krauss et al. 2009, Hoeppner and Rose 2011). When under osmotic stress, bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatic*) growth decreases, and they lose their capacity for nutrient retention and reabsorption (Pezeshki et al. 1989, Krauss et al. 2009). Mature trees subjected to prolonged exposure to salinities exceeding 1.3 ppt exhibit basal areas more than half those of trees subject to lower salinity levels (Krauss et al. 2009). Along with osmotic stress, trees exposed to salinity levels higher than 2 ppt are damaged from accumulation of salt ions (Na^+, Cl^-). This imbalance results in leaf shedding, mottling, necrotic patches on leaves, and twig die back (Krauss et al. 2009).

As in adults, prolonged exposure to high salinity levels is fatal to bald cypress and tupelo seedlings by reducing growth and photosynthetic rates; however, younger seedlings can be more susceptible to osmotic stress than older plants (Conner et al. 1997). Higher salinity levels inhibit water uptake by lowering the osmotic potential of the soil and inducing xylem cavitation and dysfunction (Kozlowski 1997, Stiller 2009). Such effects are seen in salinities as low as 0.5 ppt and, not only inhibit growth and development of seedlings and saplings, but can prohibit seed germination as well (Kozlowski 1997). Overall, when exposed to increasing salinities, bald cypress and tupelo trees exhibit a decrease in photosynthetic activity, vertical growth (Pezeshki 1990), diameter growth, root biomass (Conner et al. 1997), base area, and increased mortality rates (Krauss et al. 2009) and xylem cavitation (Stiller 2009). Decreased survival in these species increases chances of survival and dominance for more salinity-tolerant species, such as Chinese tallow (*Triadica sebiferum*) (Conner 1994).

Trees along the shoreline of the lower Neches River and sloughs of the southern portion of the Beaumont Unit were photographed during summer 2012 to document evidence of dead or dying bald cypress and water tupelo following the high salinities and aquatic hypoxia experienced by these water bodies during the 2011 drought. Recently dead trees lacked leaves or had dead foliage during the summer when healthy trees have green foliage. Recently dead trees differed from trees that had been dead for longer periods (multiple years), because the latter have sections of peeled bark that exposes bare xylem. Numerous recently dead trees were photographed along all waterways, and there also were many live trees (with green foliage) of unknown health status (Figures 21–23).

Figure 21. Photo taken May 19, 2012 along east bank of Neches River approximately 500 below the Saltwater Barrier. Visible in the photo are live bald cypress with green foliage, recently dead bald cypress lacking leaves but retaining thin branches and bark, and long dead trees lacking thin branches and bark.

Figure 22. Photo taken May 29, 2012 in Lake Bayou within the Beaumont Unit showing recently dead bald cypress trees alongside live bald cypress. Dead trees appear to be smaller and further from the shoreline.

Figure 23. Photo taken May 29, 2013 along shore of Lake Bayou within the Beaumont Unit, with several recently dead water tupelo visible in center.

Given the findings of the 2011–2012 field studies, re-establishment and protection of the recommended subsistence flows should be a critical concern for the lower Neches River and associated wetland ecosystems.

Base Flows

Recommended seasonal base flows for dry-condition years range from 1,641–2,020 cfs. These flows occurred rarely from the middle of 2009 through 2011 (Figure 19). For average-precipitation years, recommended base flows ranged from 2,583–3,207 cfs. For wet-condition years, recommended base flows ranged from 3,526–4,223 cfs. Given the lack of habitat availability data and models for aquatic organisms in the study area, it is difficult to evaluate the influence of these flows on aquatic ecology. Werner's (1982) IFIM/PHabSim study recommended maintenance flows for his upstream study reach that were from 1,000 to 5,200 cfs. Interestingly, this range of values is greater than the range of base flows calculated by HEFR across dry, average, and wet conditions for the Saltwater Barrier gage. The natural interannual variability of base flows has important ecological consequences in terms of the amount of habitat available for the various native species, with some species having a competitive advantage during dry-year base flows, and other species having an advantage during wet-year base flows (Poff et al. 1997).

High Flow Pulses

Four tiers of high flow pulses are recommended within the environmental flow regime derived from the HEFR analysis. Two-per-season flows ranges from 4,158 with a regressed volume of 16,532–77,413 acre feet (summer) to 5,378 with a regressed volume of 16,273–104,541 af (winter). One-per-season flows ranges from 5,610 cfs with a regressed volume of 28,291–132,230 af (summer) to 13,609 cfs with a regressed volume of 116,580–746,515 af (winter). The one-per-year flow is 28,685 cfs with a regressed volume of 473,089–2,502,570 af. The one-per-two year flow is 39,598 cfs with a regressed volume of 869,078–4,607,551 af.

Since early 1995, there has been an apparent reduction in the frequency and magnitude of the two highest tier flow pulses at the saltwater barrier (Figure 19). In addition to establishing river-floodplain connections and interchange of organisms, these higher-tier pulses are important for sediment dynamics, a process that was beyond the scope of the present project. High flow pulses also are critically important for maintenance of forested wetland communities in the region. The analysis performed by the NWF/GEAA provided one means to establish a relationship between river flow and the amount of riparian wetland habitat flooded. In that study, satellite images showing the extent of floodplain inundation were used with vegetation community maps to determine relationships between observed flow and percent total area of wetlands and bottomland hardwood vegetation communities inundated. At a Neches River location near the Evadale gage, 14,500 cfs was required to flood 30% of the terrain currently classified as bottomland hardwood vegetation communities. Approximately 75% of these vegetation communities were flooded at 20,000 cfs. This analysis presents a strong argument that at least the first three flow pulse tiers (two per season, one-per season, one-per year) are required to maintain the current riparian wetland communities of the lower Neches River. It also seems logical that the one-per-two-year flow pulse would be required to maintain the full extent of riparian vegetation communities of the lower Neches River.

Global Climate Change, Sea Level, and Salinity Intrusion

Two factors will require reevaluation of environmental flow regime for the lower Neches River, particularly the reach downstream from the Beaumont Saltwater Barrier. First is the plan to deepen and widen the Port Arthur Shipping Canal, which was recently approved by federal legislation. Sabine Lake is a large, shallow (~8 ft) estuary that receives freshwater from the Neches and Sabine rivers and saltwater from the Gulf of Mexico via Sabine Pass (Figure 24). Sabine Pass, a natural landscape feature, has been artificially enlarged (dredged). The Port Arthur Shipping Canal is an artificial channel dredged along the western shore of Sabine Lake in order to link the Neches and Sabine Canals to Sabine Pass. The Gulf Intracoastal Waterway links this system with the Calcasieu Lake to the East and Galveston Bay to the west. The result of this deepening and widening of channels for shipping has been significantly greater saltwater intrusion into the upper reaches of Sabine Lake as well as the lower reaches of the Neches and Sabine rivers in relation to the historical, pre-impact regime. The only ways to offset this impact is to increase freshwater flows, especially during dry periods, to counter saltwater intrusion, or to erect barriers to upstream movement of saltwater, which usually moves near the bottom of the water column as a “salt wedge”. Modeling of the physical dynamics of hydrology, hydraulics, salinity, and wind on a complex topography is a daunting endeavor. The U.S. Army Corps of Engineers undertook such an effort with a numerical model hydrodynamics and salinity in the Sabine-Neches waterway (USACE 2006/2007). Their model used a computational mesh, as a mathematical representation of the physical environment. A mesh included information on the shoreline geometry, the bathymetric features, and the bottom-type characteristics of the area, which included North to the Neches River at Evadale and the Sabine River at Ruliff, TX; East to a point approximately mid-way between the Sabine

Lake and Calcasieu Lake; South to 55 miles into the Gulf of Mexico from the Gulf shoreline; and West to a point approximately mid-way between Sabine Lake and Galveston Bay (Figure 25). The numerical model was calibrated and verified against field data (water surface elevation, discharge, velocity, salinity) collected from June–December, 2001.

Various baseline scenarios and scenarios following a project that deepens the Sabine/Neches Water Way (for commercial ship traffic from the Gulf of Mexico to Port Arthur and Beaumont) were simulated. Figure 26 represents the worst-case scenario for saltwater intrusion in the lower Neches River: low flow conditions with the model parameterized for high diffusion rates. Even under this scenario, salinities were not projected to exceed 2 ppt in the lower Neches River. However, as previously noted, during 2011, salinities throughout the study area below the Saltwater Barrier were from 7–16 ppt. The simulations for low flow conditions and lower rates of diffusion predict similar salinity values for the lower Neches River, but lower values within Sabine Lake (Figure 27). It therefore appears that the USACE salinity model is unable to predict salinity dynamics in the lower Neches River, either because the scenarios have not accounted for closure of the Saltwater Barrier and lack of flows, or other parameters in the model are insufficiently understood or calibrated for these scenarios. What we have learned from the salinity model results is that, currently, flows passing downstream from the Saltwater Barrier during periods of severe drought are insufficient to maintain the historic communities of freshwater and wetland species within the study area.

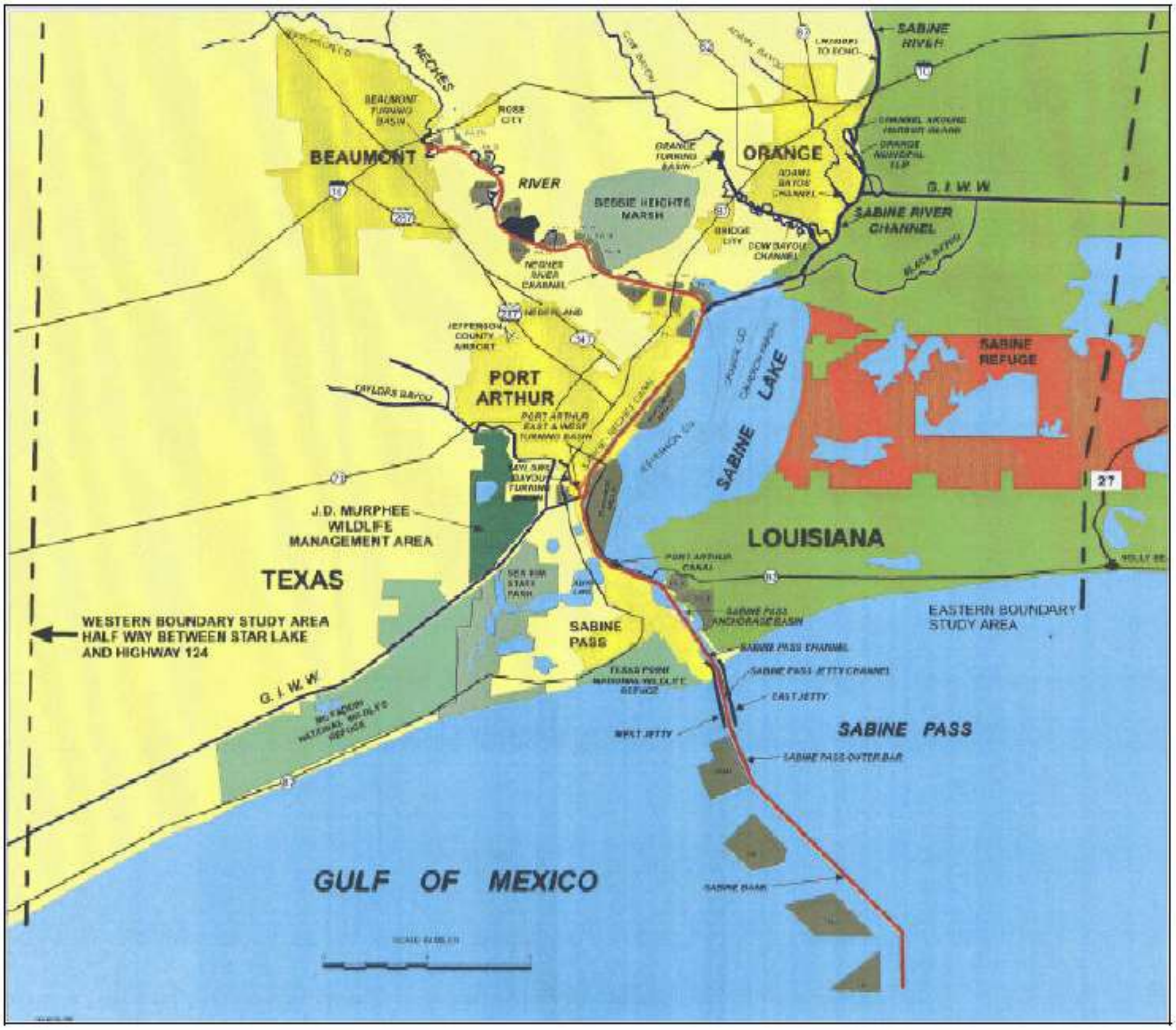

Figure 24. Map showing the Sabine Lake, Sabine Pass, the lower Neches River, Intracoastal Waterway, and the Port Arthur/Beaumont Ship Channel (from USACE 2006/2007).

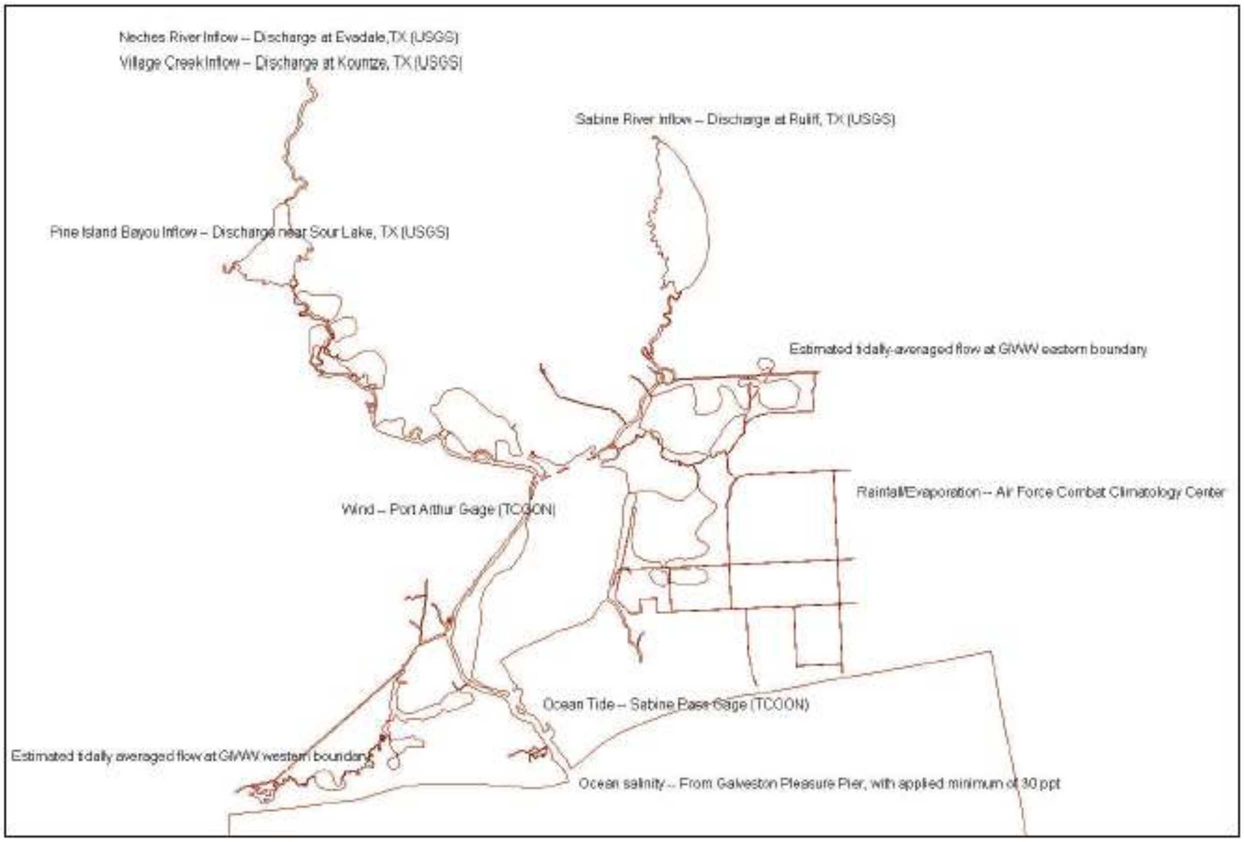

Figure 25. Map showing the spatial domain of the USACE (2006/2007) salinity model.

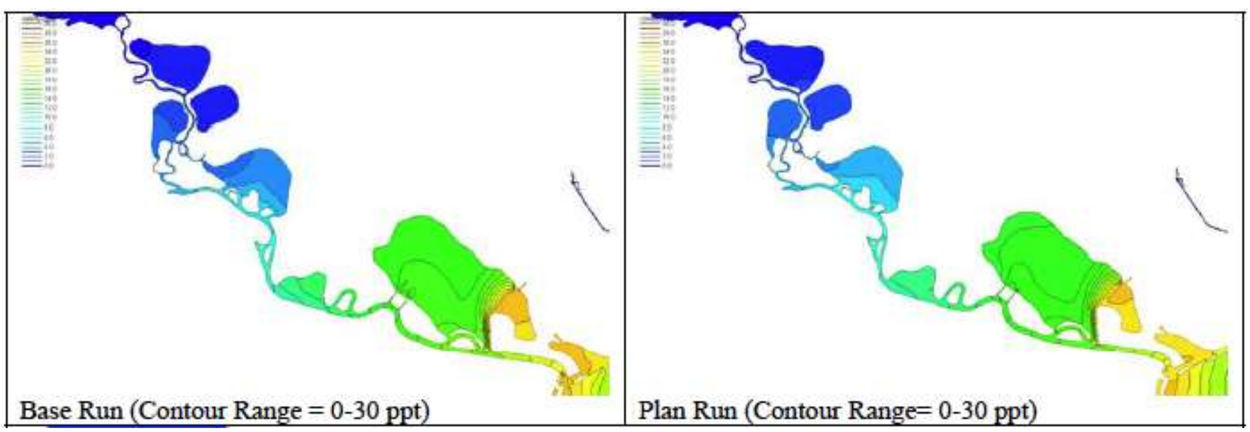

Figure 26. USACE (2006/2007) model estimates for salinity for the average base scenario and the scenario for the Plan to deepen the SNWW Plan under the low inflow from the Neches River with high channel diffusion. Dark blue is 0–2 ppt salinity, light blue is 4–10 ppt, green is 12–18 ppt, and yellow is 20–24 ppt.

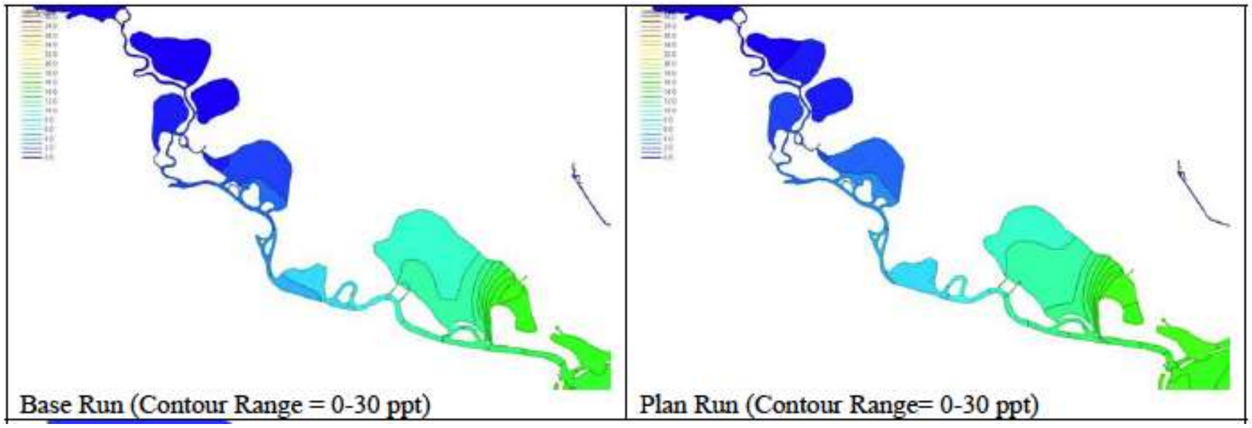

Figure 27. USACE (2006/2007) model estimates for salinity for the average base scenario and the scenario for the Plan to deepen the SNWW Plan under the low inflow from the Neches River with low channel diffusion. Dark blue is 0–2 ppt salinity, light blue is 4–10 ppt, and green is 12–30 ppt.

Senate Bill 3: Environmental Flow Recommendations, Stakeholder Input, and TCEQ's Environmental Flow Standards for Water Rights Permitting

To provide a frame of reference for recent policies that may influence implementation of environmental flows for the lower Neches River in the study area, a brief summary is provided for revision to the environmental flow regime recommendations for the Neches at Evadale and Village Creek gages under the the SB3 process. Table 12 summarizes the environmental flow regime components (subsistence, base, high flow pulses) recommended during different hydrological seasons (e.g. winter, summer, and fall) by the Sabine/Neches BBEST (2009) for Evadale and Village Creek gages. Table 13 summarizes the TCEQ's current environmental flow standards that were adopted based on input from the basin science team, basin stakeholder committee (S/N BBASC 2010), the general public, and TCEQ staff analyses. In general, the TCEQ flow regime component values are lower than those proposed by the S/N BBEST. It also is noteworthy that the Sabine/Neches BBEST flow regime has some values that are lower than those proposed by the Sabine/Neches BBEST Ecology Subcommittee that performed the biological overlay analysis (Sabine/Neches BBEST 2009, Appendix 9.3.2).

The 5th percentile of historical low flows has been adopted as the international standard for reducing risk during droughts (Acreman and Dunbar 2004). The rationale for this assessment is that, with current and future human impacts to flows, realized flows will likely fall below any given subsistence threshold at frequencies greater than those experienced historically. In fact, this is the situation on the lower Neches River today (Figures 17 and 18), and this is due to the blockage of flow by closure of the Saltwater Barrier during low-flow periods. The Saltwater Barrier fulfills its intended function, which is to prevent upstream incursion of saline water during periods of low flow. At the same time, closure of the Saltwater Barrier results in elevation of salinity in the lower Neches River and associated freshwater wetlands downstream. Therefore, whether or not the 1.7th or 5th percentile of historic flows (or another value) is adopted for subsistence flow, the current reality is that flow in the main river channel effectively is zero below the Saltwater Barrier during periods of drought. This novel situation is highly likely to result in major changes to the riparian and aquatic communities and ecosystems of the area. Moreover, a lack of flushing flows resulted in low dissolved oxygen concentrations, accumulation of dissolved organic compounds from the paper mill and perhaps other pollution, and accumulation of floating aquatic macrophytes (*Salvinia*) throughout the waterways between the saltwater barrier and Interstate 10 during the latter stages of the 2011 drought and also during the late summer of 2012.

Few high flow pulses occurred during the two-year field study; however, it was observed that fish communities responded rapidly to high flow pulses that reduced salinities and flushed pollution and mats of floating aquatic macrophytes downstream to Sabine Lake. Within several months, the lower Neches River and Sloughs of the study area within the Beaumont Unit had fish assemblages with greater numbers of species and greater proportions of freshwater and intolerant species.

Table 12. Environmental flow regimes recommended for maintenance of native biota and ecological processes for the Neches River at Evadale and Village Creek near Kountze. Derived from the Sabine/Neches BBEST biological overlay, MBFIT hydrologic separation method, and HEFR summarization (W= Winter, S= Spring, Su= Summer, F= Fall, Vol= Volume, D= Duration)

	High flows	Base flows	Subsistence flows
Neches River at Evadale	2-per-season W=2000cfs; Vol=21702; D=6 days S=3440cfs; Vol=64381; D=12 Su=1190cfs; Vol=15630; D=7 F=1150cfs; Vol=12160; D=6 1-per-season, W=8700cfs; Vol=255138; D=22 days S=8700cfs; Vol=250330; D=23 Su=3390cfs; Vol=64197; D=13 F=3820cfs; Vol=68248; D=13	W-dry year= 1760cfs W-average year=2590cfs W-wet year=4980cfs S-dry year=1553cfs S-average year= 2070cfs D-wet year=3868cfs Su-dry year= 471cfs Su-average year= 2140cfs Su-wet year= 3210cfs F-dry year= 438cfs F-average year=1280cfs F-wet year= 2630cfs	Minimum value= 228cfs for Su period; Record flows as low as 228cfs for S; and lowest flow= 226cfs S Su flow > 228cfs 41cfs more than 97% of the days F flows> 41cfs more than 95% of the days For all flows, 228cfs represents 1.7 percentile; 370cfs is 5th percentile of all flows; 1838.6cfs is the 7Q2 flow (this value is influenced by hydropower operation)
Village Creek at Kountze	2-per-season, W=2010; Vol=36927; D=13 days S=1380cfs; Vol:23093; D=13 Su=341cfs; Vol=6159; D=8 F=712cfs; Vol=11426; D=9 1-per-season, W=2070cfs; Vol=38134; D:13 days S=2070cfs; Vol=31650; D=15 Su=814cfs; Vol=11418; D=13 F=2070cfs; Vol=31143; D=13	W-dry year= 240cfs W-average year= 424cfs W-wet year= 672cfs S-dry year= 106cfs S-average year= 189cfs D-wet year= 335cfs Su-dry year= 70cfs Su-average year= 91cfs Su-wet year=135cfs F-dry year= 89cfs F-average year= 138cfs F-wet year=2 36cfs	Minimum value= 41cfs for S/F periods Lowest flow= 83cfs for W and 44cfs for S Flows in W/S month <41cfs Su flows>41cfs more than 96%of the days F flows>41cfs more than97% of the days For all flows, 41cfs represents 1.6 percentile; 61cfs is 5th percentile of all flows; 78.9 cfs is the 7Q2 flows (BBEST 2009)

Table 13. TCEQ environmental flow standards adopted for five gages in the Neches River Basin. The Sabine River near Evadale and Village Creek near Kountze appear in the two far-right columns.

Season	Flow Status	Table 2 Neches River and Tributaries Final TCEQ Adopted E-flow Standards (cfs) by location, season, and flow status NENE Neches River near Neches, TX	NERO Neches River near Rockland	ANAL Angelina River near Alto, TX	NEEV Neches River near Evadale, TX	VIKO Village Creek near Kountze, TX
Winter Jan-Feb-Mar	Subsistence	51 cfs	67 cfs	55 cfs	228 cfs	83 cfs
	Base	196 cfs	603 cfs	277 cfs	1,925 cfs	264 cfs
	Pulse	1 per season Trigger: 833 cfs Duration: 10 days Volume: 19,104 ac-ft	1 per season Trigger: 3,080 cfs Duration: 14 days Volume: 82,195 ac-ft	1 per season Trigger: 1,620 cfs Duration: 13 days Volume: 37,114 ac-ft	1 per season Trigger: 2,020 cfs Duration: 6 days Volume: 20,920 ac-ft	1 per season Trigger: 2,010 cfs Duration: 13 days Volume: 36,927 ac-ft
Spring Apr-May-Jun	Subsistence	21 cfs	29 cfs	18 cfs	266 cfs	49 cfs
	Base	96 cfs	420 cfs	90 cfs	1,804 cfs	117 cfs
	Pulse 1 per season	2 per season Trigger: 820 cfs Duration: 12 days Volume: 20,405 ac-ft	2 per season Trigger: 1,720 cfs Duration: 12 days Volume: 39,935 ac-ft	2 per season Trigger: 1,100 cfs Duration: 14 days Volume: 24,117 ac-ft	2 per season Trigger: 3,830 cfs Duration: 12 days Volume: 68,784 ac-ft	2 per season Trigger: 1,380 cfs Duration: 13 days Volume: 23,093 ac-ft
Summer Jul-Aug-Sep	Subsistence	12 cfs	21 cfs	11 cfs	288 cfs	41 cfs
	Base	46 cfs	67 cfs	40 cfs	580 cfs	77 cfs
	Pulse	1 per season Trigger: 113 cfs Duration: 4 days Volume: 1,339 ac-ft	1 per season Trigger: 195 cfs Duration: 5 days Volume: 1,548 ac-ft	1 per season Trigger: 146 cfs Duration: 8 days Volume: 2,632 ac-ft	1 per season Trigger: 1,540 cfs Duration: 9 days Volume: 21,605 ac-ft	1 per season Trigger: 341 cfs Duration: 8 days Volume: 6,159 ac-ft
Fall Oct-Nov-Dec	Subsistence	13 cfs	21 cfs	16 cfs	228 cfs	41 cfs
	Base	80 cfs	90 cfs	52 cfs	512 cfs	98 cfs
	Pulse 1 per season	2 per season Trigger: 345 cfs Duration: 8 days Volume: 5,391 ac-ft	2 per season Trigger: 515 cfs Duration: 8 days Volume: 8,172 ac-ft*	2 per season Trigger: 588 cfs Duration: 12 days Volume: 12,038 ac-ft	2 per season Trigger: 1,570 cfs Duration: 7 days Volume: 17,815 ac-ft	2 per season Trigger: 712 cfs Duration: 9 days Volume: 11,426 ac-ft

* 8,172 ac-ft is calculated based on trigger flow rate and duration as TCEQ/BBEST published number of 649 ac-ft is obvious error.

It should be noted that the base-flow and high flow pulse were reduced by the TCEQ in setting the environmental flow standards to be used for evaluation of new water rights permit applications (Roach 2013, Figure 28). Since no analysis was reported by TCEQ that demonstrates how these lower flows are likely to be protective of a sound ecological environment, it seems that the lack of higher base flows during relatively wet years (as proposed by the Sabine Neches BBEST), together with the reduced magnitude, duration and frequency of high flow pulses, will only increase risks to the bottomland hardwood forests and freshwater wetlands of the study area.

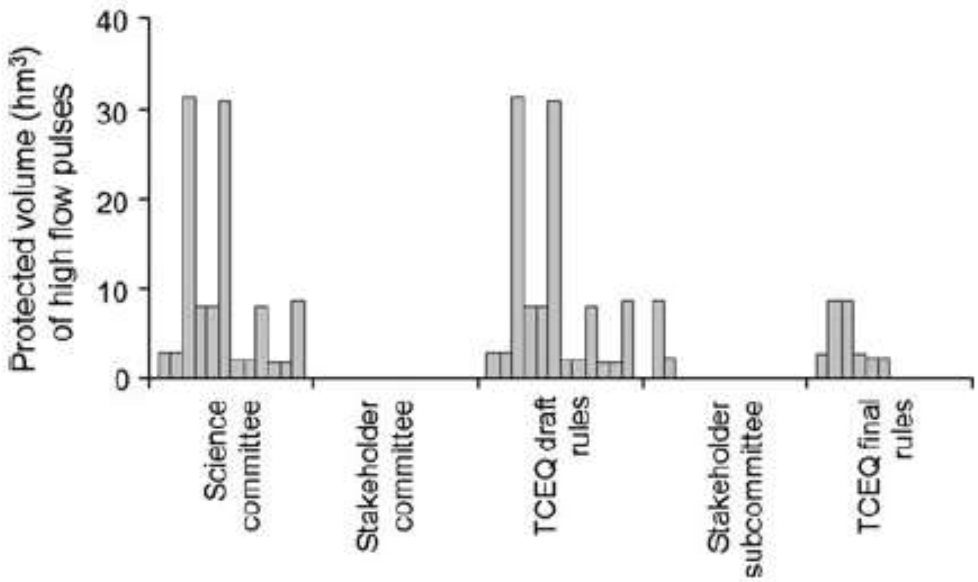

Figure 28. Figure from Roach (2011) showing reductions in high flow pulses during steps in the SB3 process that begins with the basin science committee with subsequent input from basin stakeholders, public input on draft TCEQ rules, stakeholder committee revised recommendation, and TCEQ final environmental flows standards.

NWF/GEAA performed an analysis of flow pulse magnitudes and areas of floodplain duration for four gages within the Sabine and Neches Rivers with sufficient data (Sabine/Neches BBEST 2009, Appendix 9.3.2). Their report concluded that the magnitudes of the two seasonal categories of high flow pulses obtained from HEFR analysis (two-per-season, one-per-season) were not sufficient to inundate riparian areas on an annual basis in the lower Neches River. A one-per-year high flow pulse was required to ensure that sufficient riparian inundation, lateral connectivity, and channel maintenance flows for the two lower basin gages that were analyzed. These flows also would facilitate migration and spawning of river fishes if provided during the months of February–May. Oddly, the Sabine/Neches BBEST report did not recommend any of these larger one-per year flows as part of their environmental flow regimes. The S/N BBEST report only recommended two-per-season, and one-per-season flow pulses during each of four seasons. Furthermore, the TCEQ, in setting environmental flow standards for permitting, only protected two of the two-per-season flow pulses for spring and fall, and only one one-per-season flow pulse for winter and summer (Roach 2011, Figure 28). Therefore, the high flow pulses protected under the state's current environmental flow standards are unlikely to maintain the current vegetation communities of the study are within the Beaumont Unit of the Big Thicket Preserve.

Discussion

Drought conditions lasting from October 2010 through September 2011 resulted in the driest 12-month period in Texas' recorded history, with a statewide average precipitation total of approximately 11.4 inches, surpassing the drought of 1956 by 2.4 inches (Nielsen-Gammon 2012). This lack of precipitation was reflected in the flow patterns of the Lower Neches, which exhibited a low, mostly consistent flow until larger and more frequent rainfall events occurred near the end of November 2011. Physiochemical measurements taken during this drought revealed that water quality in the lower Neches River below the Beaumont Saltwater Barrier deteriorates during extended periods of low flow. Differences in water quality measurements taken directly above and directly below the saltwater barrier indicated a clear separation between these two segments of the river during extreme low-flow periods when the barrier was closed. Seine samples obtained during October and November 2011 consisted of species tolerant to low DO and enrichment with dissolved organic compounds (DOC) as well as brackish and saline conditions. Moreover, those samples lacked minnows, sunfishes, and other indicator species intolerant of salinity, and these species were common in seine samples during summer 2012 when salinity declined to ≤ 1.5 ppt. Although conditions improved below

Top: blackwater of Lake Bayou, November 2011;
Bottom: bald cypress knees, Lake Bayou,

the barrier in December 2011, following the return of periodic rain events, the river lacked the spatial salinity gradient characteristic of coastal streams (Rakocinski et al. 1992, Jaureguizar et al. 2003, Martino and Able 2003, Albaret et al. 2004). Furthermore, the lowest DO measurement was taken just below the barrier during November, 2011 indicating that, while the barrier was closed, it is possible that tidal flux dominated downstream reaches, thereby allowing for greater saltwater intrusion and minimal flushing of paper mill effluent downstream to Sabine Lake (Harrel and Smith 2002). This lack of dilution of the paper mill effluent probably increased biological and chemical oxygen demands thereby reducing DO levels (Lima Neto et al. 2007).

Fish species common in samples during drought conditions included marine species (*Cynoscion* spp.) and two freshwater species (*L. osseus* and *D. cepedianum*) that are tolerant of degraded water quality (Linam and Kleinsasser 1998). When water quality improved during December 2011, fish assemblages showed signs of recovery; there was an increase in fish abundance, species richness, and proportions of freshwater species. Fish are highly mobile organisms, thus it is not uncommon to see rapid recovery in species richness and assemblage composition as environmental conditions improve (Sheldon and Meffe 1995, Lonzarich et al. 1998, Stevens et al. 2006). However, the rate of restoration between systems is highly variable, and species composition may deviate from the original assemblage if some species are lost from ecosystems that have undergone long-term changes or experienced repeated or chronic harsh conditions (Larimore et al. 1959, Yount and Niemi 1990, Sheldon and Meffe 1995, Lake 2003). Even though species richness from gillnet surveys conducted during May, July, and August 2012 were similar to species richness during October 2011, the 2012 samples showed evidence of further recovery and included a variety of intolerant freshwater and marine species.

1. Above saltwater barrier Nov. 2011

2. Below saltwater barrier July 2012

3. River channel close to site 5, Nov. 2011

4. River channel close to site 5, July 2012

5. 10 Mile Bayou, Nov. 2011

6. 10 Mile Bayou, August 2012

Photos from survey sites on various dates. Photos 2 and 6 show water fern (*Salvinia* sp cf *minima*) covering the water surface. The thick mat of vegetation prevents sunlight from reaching the water and reduces dissolved oxygen content.

Fish species richness was higher during summer 2012 than fall 2011 at the peak of the drought. A mixture of intolerant and tolerant fish species was present in seine samples from most sites during 2012. In contrast to results from seine data, gillnet samples revealed weak patterns in assemblage structure based on location relative to the Saltwater Barrier and sampling period. Fishes captured in gillnets included many species tolerant of low DO, high concentrations of dissolved organic compounds, and brackish water (e.g., gars, channel catfish, largemouth bass). A possible explanation is that these larger species are capable of moving greater distances over short time periods (Lonzarich et al. 1998, Hubert et al. 2012). Larger fishes typically have larger home ranges (i.e., areas visited by an individual fish over a period of days) presumably due to their higher energy demands that require foraging over larger areas (Gerking 1953, Lonzarich et al. 1998, Kramer and Chapman 1999). Further, larger fishes are less susceptible to predation than smaller fishes, so that larger fishes can venture farther from structurally complex habitats that provide smaller fishes with refuge from predators (Mittelbach 1981, Schlosser 1987, Chick and Mlvor 1997).

On average, fish samples taken while the Saltwater Barrier gates were open had significantly higher species richness than samples taken while the gates was closed. Moreover, samples taken above the barrier had more species than samples taken below the barrier, regardless of sampling period. Species assemblage patterns observed among sites and sampling periods during summer 2012 were generally consistent with results seen in previous studies along the same stretch of river. Harrel (1975) analyzed water quality and assemblages of benthic macroinvertebrates of the Neches above and below temporary saltwater barriers (prior to the construction of the permanent saltwater barrier in 2003, a pair of temporary installments were used for a similar purpose to the permanent barrier used now) and found lower water quality and species richness below the barrier as compared to sites above the barrier. Harrel and Smith (2002) conducted a similar study in the following decades after enactment of new regulations and improved water treatment. They documented improvement in water quality and species richness at sites below the barrier, except for two sites in closest proximity to the MeadWestvaco paper mill effluent discharge that continued to show evidence of high DOC and low DO (Harrel and Smith 2002). Similar results were observed in seine samples during summer 2012; regardless of whether the barrier was open or closed, species richness was lowest in sites closest to the location of the paper mill effluent discharge pipe. Although there seems to be some improvement in water quality between Harrel and Smith's study and the current study, there remains evidence of impact on species assemblages at sites near the effluent discharge pipe, especially during times of low flow.

Throughout summer 2012, freshwater fishes were more abundant and diverse at sites above the barrier; downstream sites (closer to Sabine Lake) revealed greater dominance of marine and estuarine species. Despite relatively low salinities during July 2012, freshwater fish distributions may have been more restricted during that period due to DO levels in areas below the barrier (McKinsey and Chapman 1998, Kramer and Chapman 1999, Stevens et al. 2006). Certain freshwater species, such as *Percina sciera, A. grunniens* and *N. volucellus*, were restricted to sites above the barrier during every survey period. Other species were primarily found at sites above the barrier when the barrier was closed and were collected below the barrier when it was open. Multivariate analysis revealed distinct assemblage patterns at sites above the barriers across all months. Thus, it appears that the saltwater barrier may hinder dispersal by certain species regardless of whether it is open or closed.

Relationships between salinity gradients and fish assemblages, such as those observed in the Lower Neches, have been observed in estuarine ecosystems worldwide (Keup and Bayless 1964, Garcia et al. 2003b, Martino and Able 2003, Whitfield et al. 2006). Strong variation in precipitation and runoff can shift longitudinal spatial patterns of salinity gradients and fish assemblages (Garcia et al. 2003a, Love et al. 2008, Vivier et al. 2010, Zampatti et al. 2010). Coastal streams and estuaries play important roles in recruitment of marine species that depend on estuarine gradients and access to oligohaline habitats (Rogers et al. 1984, Akin et al. 2003), and chronic high salinities may have detrimental effects on these marine populations (Roessig et al. 2004, Dolbeth et al. 2008). Zampatti et al. (2010) observed a large decline in recruitment of estuarine-dependent marine species in an Australian estuary as freshwater flow from the contributing river decreased over a three-year period. Saltwater intrusion in the Lower Neches also could impact estuarine-dependent species, such as red drum, Gulf menhaden, and bay whiff. These fishes depend on oligohaline coastal ecosystems for optimal juvenile growth and survival, as well as crustacean production that provides important food resources (Deegan 1990, Reichert and van der Veer 1991, Raynie and Shaw 1994, Craig et al. 1995, Roessig et al. 2004).

In addition to analyzing relationships between flow, physiochemical environmental parameters and spatiotemporal variation in fish assemblages, this project examined how drought and low flows may affect riparian and wetland ecosystems of the study area. In November 2011, just before the drought began to break, salinity levels below the saltwater barrier had exceeded tolerance levels for the dominant tree species (bald cypress and water tupelo) of the bottomland hardwood forest (Krauss et al. 2009, Hoeppner and Rose 2011). During 2012, evidence of stress and mortality was observed among trees near the Neches riverbanks below the saltwater barrier (Figures 18–20). Such evidence was not observed at locations above the barrier. Bald cypress is reported to be the most saline-tolerant floodplain hardwood species of Gulf coast bottomland forests. Nonetheless, adult trees are only able to withstand chronic salinity exposure up to approximately 3–4 ppt on average before they are adversely affected (Krauss et al. 2007). It is important to note that salinity tolerances vary between populations (Conner and Inabinette 2005, Krauss et al. 2007). For example, Krauss et al. (2009) observed that basal area growth decreased approximately 50% over a four year study period for adults in sites with salinities of 1.3 ppt and greater. For seedlings, experiments have revealed 100% mortality after two weeks at 10 ppt, 73% mortality after three months at 8 ppt, and detrimental effects to growth at salinities over 2 ppt (Conner et al. 1997, Krauss et al. 2007). Further, as Hackney et al. (2007) discovered, low flows resulting in saltwater intrusion also can lead to conversion of freshwater marsh within this area into brackish or saltwater marsh at salinity levels around 2 ppt, and this change may occur in as little as four months.

Environmental Flow Recommendations for the Lower Neches River Study Area

An environmental flow regime was defined by Texas Senate Bill 3 as "*a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies*." The methodologies employed by the Sabine-Neches BBEST were employed herein to estimate the environmental flow regime for the lower Neches River below the Saltwater Barrier gage. This method requires analysis of historical stream-flow data using a hydrographic separation tool (MBFIT) and Hydrology-Based Environmental Flow Regime (HEFR) program to summarize flow regime components that are selected based on inputs that address climatic and ecological factors. In order to accomplish this, a longer-term flow record had to be extrapolated for the Saltwater Barrier gage using data from three upstream gages. Output from HEFR consists of tiered environmental flow regime components for designated seasons and annual conditions of precipitation (for base flows). These tiered regime components were then evaluated with respect to water quality and the life history requirements of aquatic and riparian species, particularly the subset of indicator fish species.

One shortcoming in the Environmental Flows Recommendations Report issued by the Sabine-Neches BBEST (2009) was the assumption that environmental flows recommended for the gages in the lowest reaches of the basins will provide flows adequate for maintaining a sound ecological environment downstream within the estuary (i.e., lower Sabine River and Sabine Lake). This assumption leaves a spatial gap in the analysis for Neches River habitats below the Neches-Evadale and Village Creek USGS gages. The Lower Cypress tract and its bayous are situated within that spatial gap, a region of the lower Neches River just below the Saltwater Barrier and encompassing the tidally influenced portion of the lower Neches River. Comparison of flows measured at the Saltwater Barrier the past 9 years with data extrapolated from the upstream gages revealed significant periods of water deficit for the lower Neches. This deficit defined by less water passing downstream from the barrier relative to the amount of water that passes to the barrier from upstream barrier. This calculation was conservative because it did not account for local inflows or any municipal, industrial, or agricultural diversions. In fact, these diversions may account for part of the flow deficit below the Saltwater Barrier. Clearly, the major challenge confronting the lower Neches River and ecosystems of the Beaumont Unit located downstream from the Saltwater Barrier is establishment and protection of subsistence flows. During the 2011 drought, the flows were 0 cfs for major periods, and the result was high salinity, reduced dissolved oxygen due to lack of flushing of paper mill effluents, and reduction of aquatic biodiversity from loss of intolerant aquatic species.

Recommended Monitoring

1. A water-quality monitoring program is needed within lower Neches below the barrier near the MeadWestvaco paper mill discharge and within the bayous of the Beaumont Unit. Obviously the intensity of this monitoring would depend on human and financial resources, but ideally it should be done on a weekly basis during the hot summer months when dissolved oxygen levels may be low, especially during periods of drought. Weekly water quality monitoring would allow for forecasting levels of degradation that trigger acute mortality of aquatic animals and riparian trees. During other seasons, water quality monitoring could be performed once per month given that this frequency of sampling is capable of revealing temporal and spatial trends. The locations and time intervals for the water-quality monitoring program conducted by the LNVRA appear to be inadequate to reveal degradation during drought conditions when dissolved organic compounds from the paper mill effluent accumulate when there is a lack of stream flow, and when the salt wedge advances to the saltwater barrier and brackish water invades the freshwater wetlands.

2. Periodic fish surveys (monthly or quarterly) would allow for a more detailed analysis of spatial and temporal variation in species assemblage structure and inferences about the environmental factors that account for this variation. The

present study revealed patterns and relationships during a period of extreme drought followed by a brief interval of recovery, and therefore is particularly useful for informing subsistence flow and base flow requirements during dry years. Long-term surveys using standardized methodologies at strategic locations would allow evaluation of all components of the environmental flow regime across a range of climatic conditions. Seine samples yielded more species and more indicator species and therefore would be a priority. However, gillnet sampling (and fykenet sampling) would be complementary to reveal trends in species important for fisheries and that also are excellent indicators of salinity trends.

3. The dynamics of vegetation communities within the Lower Beaumont Unit should be studied in detail, because conditions are likely to change given the current human impacts to hydrology, pollution from the paper mill, the deepening of the Sabine Ship Channel (Brown and Stokes 2009), and predicted impacts of climate change to coastal areas of the Gulf of Mexico. With the deepening of the ship channel and increases in sea level of up to 1 cm per year, salinities are likely to increase, and duration of brackish conditions will have greater duration within the lower Neches River and wetlands of the Beaumont Unit. Vegetation communities will change in response to new hydrological and salinity regimes, with halophytic herbaceous wetland plants eventually replacing hardwoods such as bald cypress and water tupelo (Williams et al. 1999). The recruitment dynamics, growth, and mortality of bald cypress and water tupelo should be monitored and analyzed in relation to physicochemical and hydrologic data.

Conclusions

Areas of transition between freshwater and marine ecosystems typically exhibit environmental gradients, particularly with regard to salinity, that influences fish assemblages in fairly predictable ways. The Neches River and sloughs within the

Beaumont Unit during 2011–2012 had higher salinity and impaired water quality during periods of drought. To maintain freshwater and native riparian biodiversity within the Lower Neches, subsistence flows should be passed across the Saltwater Barrier to maintain a freshwater lens above the encroaching saltwater wedge. The current state water plan proposes to meet increasing water demands of a growing population with additional diversions from streams and rivers of East Texas, which could further reduce instream flows during periods leading up to and during droughts. These flow reductions would only increase the severity of impacts to native ecosystems during drought.

As Texas strives to satisfy the water needs of a growing population and economy, one means of addressing the challenge of protecting natural assets would be a campaign to educate the public regarding tradeoffs and the need for water conservation, even in southeastern Texas, a relatively water-rich region. Greater access to knowledge and tools for more efficient water use could reduce water waste, water demand, and the need for additional surface-water diversions. With regard to the lack of downstream flushing of paper mill effluent in the Lower Neches during times of drought, it may be necessary for government agencies to re-evaluate and perhaps revise the current permit of allowable daily discharge from the Mead Westvaco paper mill to account for impacts during periods of low instream flows. Currently, TPDES Permit No WQ0000493000 allows for a daily discharge of 65 million gallons per day. To protect environmental quality, biodiversity, and ecosystem services, this discharge should be reduced during periods of severe drought.

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